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CONTENTS

No. 1. JANUARY

No. 2. FEBRUARY

No. 3. MARCH

No. 4. APRIL

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THE PUBESCENT CHARACTERISTIC OF RED CLOVER, *TRIFOLIUM PRATENSE*, AS RELATED TO THE DETERMINATION OF ORIGIN OF THE SEED[1]

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RED clover, *Trifolium pratense*, is composed of a great variety of ecotypes and biotypes of the two distinct forms, double cut and single cut, known generally in the United States as medium red clover and mammoth red clover, respectively. The development of these types has been and is still being rapidly facilitated because red clover is for all practical purposes self sterile, and is, therefore, in a hybrid condition. Whenever one or more factors of the environment, such as diseases or insects, adversely affect the plants either by killing outright or reducing their growth to the point of impairment of seed production, the susceptible types are eliminated rapidly. The less adverse factors of the environment, such as different photoperiods, change the type more gradually.

Red clover is one of the most widely used legumes throughout Europe and the United States, but it is not indigenous to the United States, having been introduced from Europe by the early settlers. Since that time, depending upon the environment, many domestic ecotypes and biotypes have developed, distinguishable only when grown in the field, under selective environmental influences. Of particular interest in connection with the subject of this paper has been the development in the United States and Canada of a red clover form in which the pubescence is attached at right angles to the stems and leaf petioles and which may be descriptively called rough pubescence. On the European agricultural forms the pubescence is generally appressed but the plants are commonly classified as being smooth. (Figs. 1, 2, and 3.) Since American red clover is of European origin, it has been suggested by Pieters (1)[3] that the rough pubescent characteristic of American red clover has resulted from the survival of the segregates possessing this characteristic when the plants were sub-

[1]Contribution from the Division of Forage Crops and Diseases. Presented at the 31st annual meeting of the Association of Official Seed Analysts, Aug. 1, 1939, Madison, Wis. Received for publication September 29, 1939.
[2]Senior Agronomist. Grateful acknowledgment is made to W. A. Davidson, Enforcement of the Federal Seed Act, Agricultural Marketing Service, U. S. Dept. of Agriculture, for facilities and assistance in conducting this study.
[3]Figures in parenthesis refer to "Literature Cited", p. 10.

jected to infestations of the potato leafhopper, *Empoasca fabae*. In comparative trials this leafhopper has shown a marked preference for the European forms.

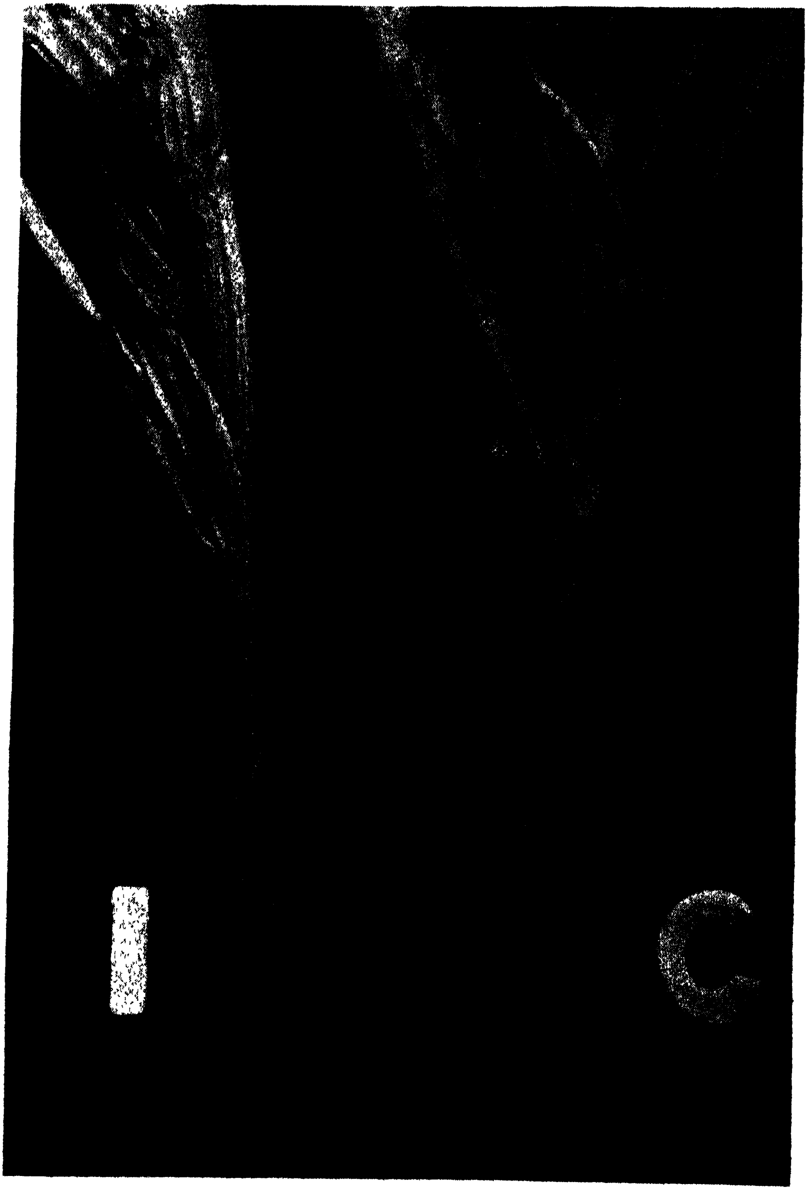

FIG. 1.—Types of pubescence on flowering stems of red clover plants. Stem on left European form, stem on right American form. (Magnified.)

The amount of pubescence varies greatly in any population of red clover plants, but in general, the American forms are much more pubescent than the European. With an increase in age of the stem and leaf petiole tissue and exposure to climatic conditions, such as rain and wind, it is believed that the pubescence becomes more brittle and either breaks off or aborts. Examinations of populations of wild red clover plants, representing the prototype of red clover, have revealed considerable variation between individual plants with regard to pubescence. Whether wild red clover or the rough pubescent plants less frequently found in the present European forms were the prototype of the American forms early records have not revealed.

Since 1922, hundreds of lots and varieties of red clover representing many different ecotypes and biotypes of European, domestic, and Canadian sources have been studied with regard to their adaptation in the principal red clover belt of the United States. In connection with this investigation, observations on populations of the agronomic European forms have shown that, in general, over 90% of the plants have appressed pubescence. Without critical inspection, many of these appear glabrous but upon closer scrutiny are seen to have a few trichomes or hairs. On the other hand, populations of plants of domestic sources grown in this country for many years without the admixture of other types, generally have less than 10% of plants with appressed pubescence. Similar results were obtained when seedling plants grown in the greenhouse from European and American seed were examined.

From an examination of cultivated and wild Norwegian types of red clover, Wexelsen (2) showed that 4% of the plants of the wild red clover had pubescence standing at right angles to the stem, while 77% of the plants had a relatively small amount of appressed pubescence. Of the cultivated races 1.4% of the plants were roughly pubescent and 88% appressed. Williams (3), in a study of the pubescence of red clover, found that 98% of the plants of American single cut or mammoth had rough pubescence, while only 10% of the Montgomery variety (English single cut, one of the most pubescent European varieties) had rough pubescence. In addition to the difference in position of the pubescence between the American and European forms, repeated observations of large populations have shown an apparent though less marked difference in the form of the tips of mature leaflets. Those of the European forms are more curved or keel-shaped than the leaflet tips of the American forms.

Agronomic forms may be classified into four general groups, American double cut, European double cut, American single cut, and European single cut. Seed of these forms is indistinguishable. The plants of each may be readily recognized, however, if grown to maturity, with the exception that the later-maturing double cut varieties and strains are somewhat similar to the early-maturing single cuts. Under normal light conditions, the single and double cut forms cannot be distinguished in the early seedling stage. Studies by Chmelar and Mostovoj (4) and by Itzerott (5), however, indicate that by the use of continued illumination, a large proportion of the plants of the double cut forms began to develop flowering stems 15 to 21 days after

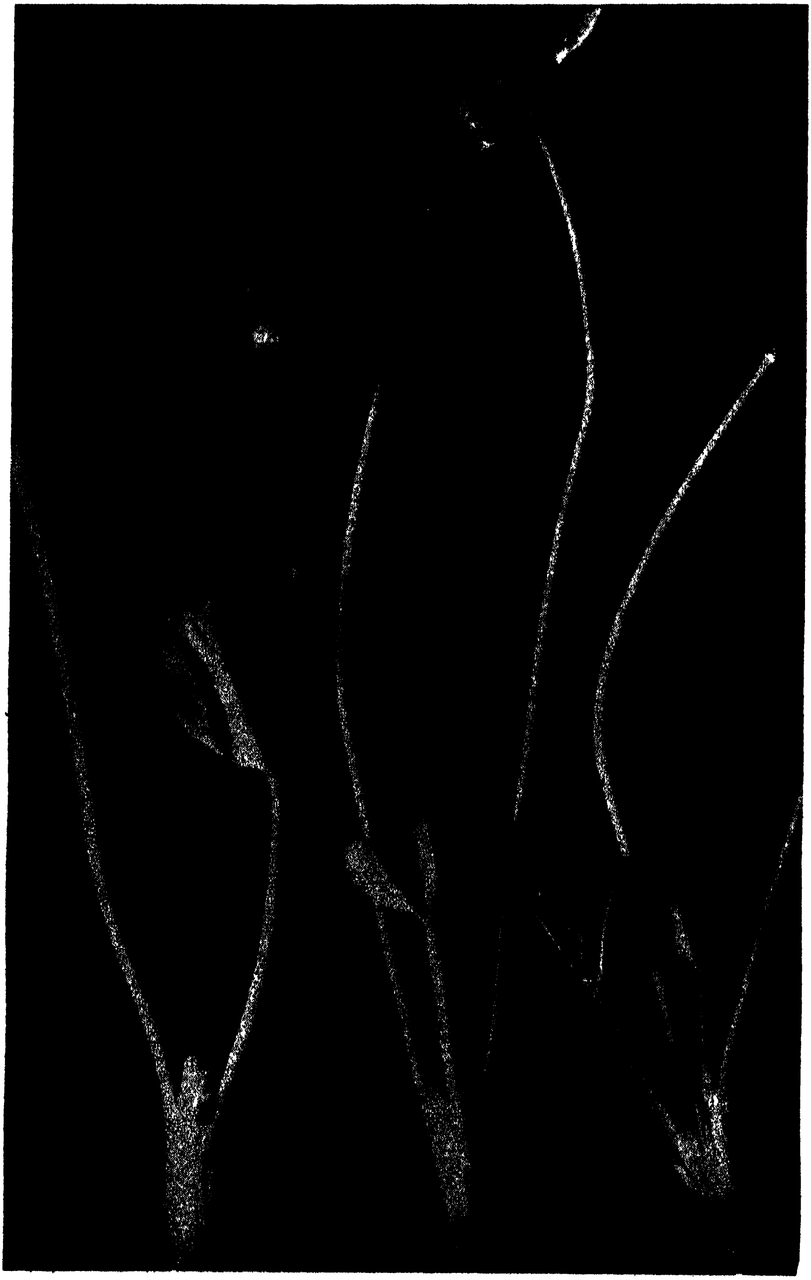

FIG. 2.—Type of pubescence of leaf petioles of seedling plants of the American form of red clover. (Natural size.)

germination, whereas, the development of the flowering stem in the single cut forms was much delayed. Considerable variation existed within every variety or lot studied indicating a lack of homozygosity for this character.

With the development of international commerce during the last 30 years, large quantities of red clover seed have been imported into the United States. Red clover seed has been handled as a commodity rather than as a living genetic entity and without regard to the adaptation of the plants to the environment where used. The seeds have

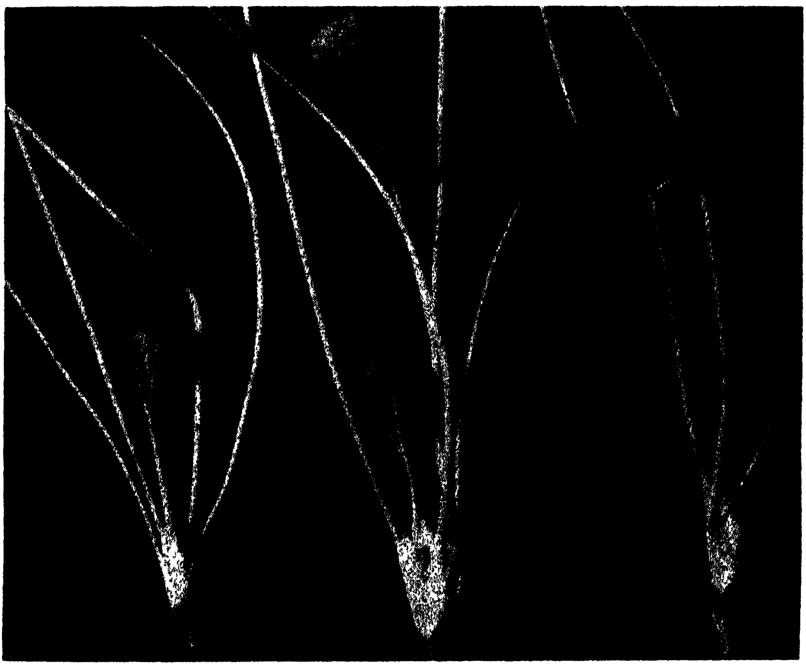

FIG. 3.—Type of pubescense on leaf petioles of seedling plants of the European form of red clover. (Natural size.)

been mixed and blended in accordance with the practices of the seed trade. The plants from such seed have been cross pollinated, thus combining the undesirable with the desirable characteristics. The level of adaptation of the crop has been decreased resulting in lower productivity and in many instances in complete losses. The movement of domestic red clover seed from a section where a certain strain is adapted to another where it is not so well adapted may also result in lower yields and losses in stand.

Since the European forms of red clover are not adapted to the principal part of the red clover belt of the United States, and since seed of the various forms cannot be distinguished, it seemed desirable to find a method more rapid than the field growing of all lots to determine the presence of the different forms. It is believed that the study here reported offers such a method.

In the enforcement of the federal seed act, samples are drawn from all imported lots of red clover seed and tested for germination and purity. In the winter of 1937–38, A. F. Musil found European weed seeds in several Canadian importations which raised the question as to the origin of the seed. Representative lots of Canadian-grown seed previously studied were of the American form resembling that grown in the United States, and if seed of Canadian and European forms has been mixed, or if pure European seed has been substituted, early confirmation of that fact would be desirable. In cooperation with those engaged in the enforcement of the federal seed act, greenhouse plantings, chiefly of the Canadian importations, were made in the fall and winter of 1938–39. The 122 lots of Canadian red clover seed studied represented importations made mostly during the period when the Canadian government had revoked the regulation requiring the staining of red clover seed imported from Great Britain. Seed imported into Canada from Great Britain during that period could have been blended with or substituted for Canadian seed and imported into the United States without being detected other than through the presence of European weed seed not common to the Canadian flora. Two hundred seeds of each lot were planted in flats 3 x 12 x 18 inches, spacing the rows 1½ inches apart and the seed ¾ of an inch apart in the row. When the plants were from 4 to 6 inches tall they were dug and each one classified as to the character of the pubescence. New growth or young tissue provides the most suitable part of the plant for observing this characteristic. The time of observation after planting varied from 6 weeks to 3 months, depending upon the date when sown. Growth was particularly slow when plantings were made during the winter solstice or when much cloudy weather prevailed, but facilities did not permit increasing the day length. The plants were classified into three groups, *viz.*, rough pubescence, appressed pubescence, and doubtful. Plants were recorded as doubtful when the pubescence was of such nature that it could not be accurately classified. In making the classification, experience gained from the observation of large populations of plants differing in pubescence is necessary to an accurate evaluation of the character of the pubescence. This is particularly true when young seedlings are examined, as the leaf petioles of the older leaves are less pubescent than the younger.

DISCUSSION

The results of this study as given in Fig. 4 show the value of the type of the pubescence of seedling plants in determining the origin of red clover seed. Of the 122 Canadian importations studied, 89, or 83.7%, produced plants with rough pubescence and may therefore be considered representative of American single or double cut forms. Twenty-one lots, or 17.2%, contained from 10 to 20% of forms with appressed pubescence, while the remaining 12 lots, or 9.1%, produced plants with very significant percentages which were definitely of European forms not adapted to the principal red clover belt of the United States. Of the plants from the 122 Canadian lots, those on which the type of pubescence was doubtful amounted to an average of approximately 3% with a range from zero to 10%. The few lots of

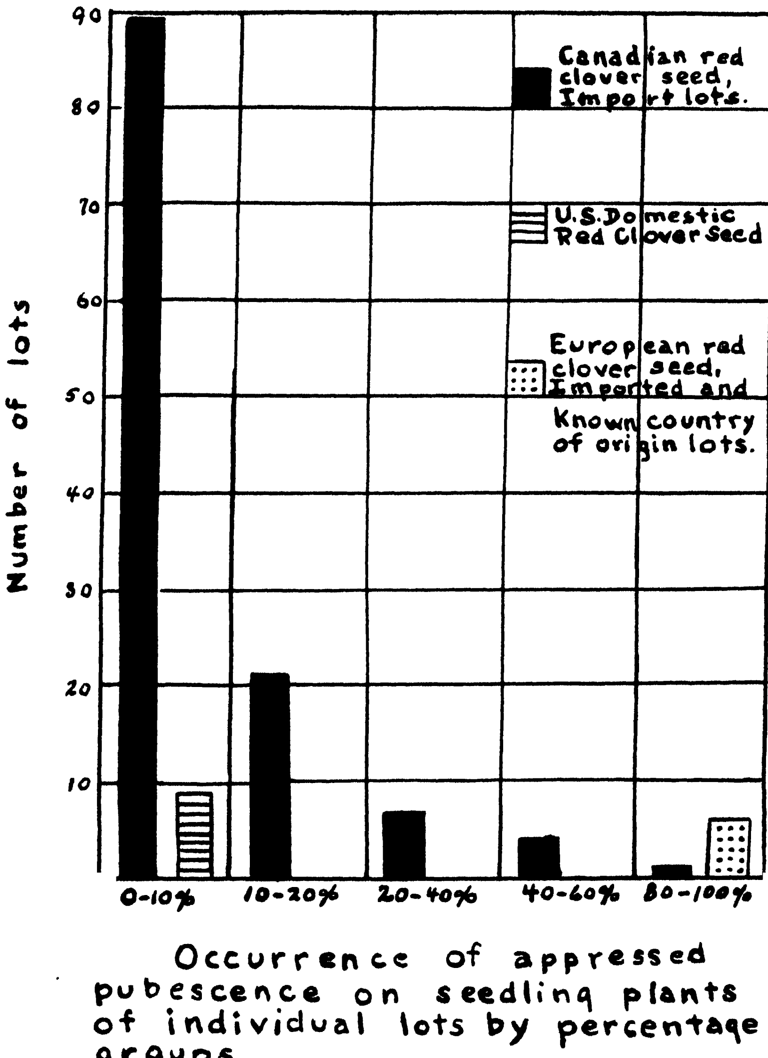

FIG. 4.—Results of greenhouse studies on the classification of seedling plants for appressed pubescence from imported Çanadian red clover seed, U. S. domestic red clover seed, and European red clover seed from imported and known country of origin lots, Washington, D. C., 1938–39.

domestic and European seed, included in these studies for comparative purposes in recording the classifications, are not representative of the variation that may be expected from an investigation of a large number of lots of commercial seed.

The results of a preliminary experiment in which artificial mixtures of American and European forms were made in varying percentages of each by weight are interesting. Considering seed size and labora-

tory germination of the original samples, the same relative proportions of the two forms were recovered when the seedling plants were classified on the pubescent characteristic.

These results, without the supporting evidence presented in the next section, should not be interpreted to mean that European clover seed was mixed with Canadian red clover seed before importation into the United States. While it may be true that such was the case, it is possible that the European forms had been grown in Canada for one or more generations and the resulting progenies could be legally classified as Canadian seed even though the lots contained varying amounts of the European forms.

After this problem was called to the attention of the Canadian authorities, every effort was made by them to insure that each lot of seed exported to the United States was the product of Canadian grown seed and that such seed was accompanied by an official Canadian certificate. Since September 15, 1938, the Canadian Government has required that all seed of European sources other than Italian be stained green before admission into Canada. This should eliminate the direct mixing of European seed with Canadian seed, but does not obviate the presence of European forms in Canadian seed after such seed is grown for one or more generations in Canada.

Furthermore, it is of interest in connection with this problem to know that the Altaswede variety, a selection of Swedish single cut red clover with appressed pubescence developed at the University of Alberta, is rather widely used in western Canada and the imported lots containing the European forms may represent this variety or mixtures thereof.

The finding of European forms is not unexpected, since these forms have been grown elsewhere in Canada and undoubtedly harvested for seed. When European forms are imported into the United States a similar condition prevails here for during the years when the environmental factors, adverse to the European forms, are not severe, survival often occurs and a partial seed crop may be obtained. Seed harvested from a 40-acre field of European double cut red clover grown in central Illinois produced a similar proportion of plants with appressed pubescence as the plants from seed imported direct from Europe.

Furthermore, in some sections of the Pacific Northwestern States the European forms are nearly as productive as the American forms and if seed of the European forms is used, a similar problem exists in regard to the presence of European forms in domestic seed.

It is not known how long the European forms or segregates from hybridization between the American and European forms will persist when grown under environmental conditions to which they are not adapted. While preliminary studies on the inheritance of the position of the pubescence of red clover have been attempted the parental material was not homozygous for this characteristic and the readings of the F_2 population were indefinite.

WEED SEED IN EUROPEAN RED CLOVER SEED

The presence of European weed seed in imported red clover seed presents an interesting question as to the origin of the red clover seed. If the most common European weed seeds found in imported European red clover seed are not found in numerous lots of red clover seed known to have been grown in the United States and Canada, empirical evidence would indicate that the European red clover seed has been mixed with the domestic and Canadian seed and had not originated as first generation seed from previous plantings. In adaptation and yield investigations of hundreds of lots of imported European red clover seed containing varying percentages of European weed seed, plants of these weed species have not been observed growing in the plots either the first or second year after planting.

In a preliminary study in cooperation with the Division of Seed Investigations, a sample of Canadian imported red clover was selected and to this was added a known quantity of weed and other crop seeds which appear as common impurities in European grown red clover seed, namely, *Picris echioides*, *Anagallis arvensis*, *Reseda* sp., *Galeopsis ladanum*, *Scleranthus annuus*, *Carduus acanthoides*, *Centaurea* spp., *Torilis* spp., *Delphinium* sp., and *Lotus corniculatus*. The weed seeds were separated from other imported samples of European red clover seed and added to the original sample to provide a greater percentage of weed seed for determining whether the weed seed would produce plants that would reproduce when sown with the red clover seed.

The sample was divided and seeded in small plots at Ithaca, New York; Madison, Wisconsin; Lexington, Kentucky; and Urbana, Illinois, in the spring of 1938. Frequent observations on the flora of these plots were made throughout the first and second season. Germination tests were not conducted on the weed seed so the viability was not known; however, as previously mentioned, most of the seed was from several imported lots of red clover seed, and represents the European weed seed which normally occurs in the importations.

The results of these plantings are as follows: At Lexington, Kentucky, plants of none of the species included in the sample were found during the first or second year; at Urbana, Illinois, one plant of *Lotus corniculatus*, and at Ithaca, New York, one plant each of *Picris echioides* and *Lotus corniculatus* were found the second year, while at Madison, Wisconsin, two plants of *Picris echioides* were found in the fall of the first year. These plots were plowed in the fall of the first year and the survival the second year could not be determined.

The analysis of the weed seed content of the 122 lots of imported Canadian seed at time of entry into the United States by A. F. Musil of the Division of Seed Investigations resulted in 11 lots that were considered questionable as to source of origin because of the presence of European weed seed.

The appressed pubescence of the seedling plants of these same lots in the greenhouse studies with the same classification as used in Fig. 4 are as follows: One lot in the 80–100 percentage group, four lots in the 40–60 percentage group, five lots in the 20–40 percentage group, and one lot in the 10–20 percentage group. Referring to Fig. 4,

it may be seen that these questionable lots comprise all but two of the lots having 20% or more of appressed pubsecent plants.

From extensive examinations of samples of Canadian red clover seed, Musil (6) reports that certain weed seeds characteristic of European red clover are not found in Canadian red clover seed and this is further substantiated by the significant fact that European weed seeds were not found in the 89 samples in which the number of seedlings having appressed pubescence fell into the class of 0 to 10% group and only 1 out of 21 lots of the 10 to 20% group contained European weed seed. The striking relationship between the presence of European forms and the presence of European weed seed in these lots and the apparent fact that characteristic European weeds of imported red clover seed are not found in Canadian and domestic red clover seed would indicate that European seed had been mixed with Canadian seed and in the case of one lot substituted for Canadian seed. It would seem that further studies of the weed flora of the red clover seed producing sections of Canada, and ecological and life history studies of the principal European weeds found in European red clover seed not found in Canadian and United States grown seed, will contribute to a solution of this problem.

The importation of European forms of red clover unadapted in the United States is one means by which the productivity of red clover is lowered and it is of little wonder that red clover failures become more frequent and that the potentialities of a valuable crop are reduced.

CONCLUSIONS

The results of these studies indicate that the seedling plants of European forms of red clover having appressed pubescence can be distinguished from the rough pubescent American forms in greenhouse plantings and that this affords a method suitable for rapid analysis to determine the proportion of each form in a sample of red clover seed.

The identification of European forms in imported lots of Canadian red clover seed of itself would not necessarily mean that European red clover seed had been mixed or blended with Canadian seed before importation. The presence of characteristic European weed seed in imported Canadian red clover seed lots containing a high percentage of European forms of red clover does appear to indicate that in some cases European red clover seed has been blended with or substituted for Canadian grown seed.

This conclusion seems justified since characteristic European weed seeds found in European red clover seed are not found in samples of red clover seed grown in the United States and Canada.

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HYBRIDIZING OATS TO COMBINE GROWTH FOR WINTER PASTURE, HARDINESS, AND RESISTANCE TO RUSTS AND SMUTS[1]

H. R. Rosen, L. M. Weetman, and C. K. McClelland[2]

ONE of the important agricultural problems of Arkansas and the South as a whole is concerned with a frequent shortage of home-grown feed for livestock, particularly during the winter months. (There is also a shortage of livestock.)

To meet this problem, the breeding of oat varieties which would combine hardiness and good winter growth with resistance to rusts and smuts appeared exceptionally promising. The outstanding work of Stanton, Murphy, Coffman, and Humphrey[3] of the U. S. Dept. of Agriculture, in which they were able to combine resistance to crown rust, stem rust, and smuts in oats, made it immediately possible to obtain from them varieties possessing these characters and to cross them with others which possessed either hardiness or made good winter growth.

The commercial varieties of oats available at present for fall sowing, or so-called winter oats, fall into one of two groups, *viz.*, the red oat group represented mainly by Red Rustproof and its numerous derivatives, and a mixed lot in which Winter Turf, Hairy Culberson, Coker's 32–1, Lee, and Custis are common representatives. The Red Rustproof group may be characterized as making fair or mediocre winter growth, possessing slight hardiness, but capable of escaping crown rust to a considerable degree, (under natural conditions but not in the greenhouse), and also showing some degree of resistance to smuts. The varieties mentioned in the mixed lot, with the exception of Coker's 32–1, do not make much winter growth, but are much hardier than the Red Rustproof group. Unfortunately, these hardy oats are all very susceptible to the races of crown rust common in the South.

So far as hardiness is concerned, in addition to the varieties mentioned, N. I. Hancock of the Tennessee Agricultural Experiment Station and C. B. Cross of the Oklahoma Agricultural Experiment Station have made valuable selections from Winter Fulghum 2499 and from a U. S. Dept. of Agriculture hybrid, Hairy Culberson × Winter Fulghum. Some of these selections have shown even greater hardiness than any other variety tested.

In beginning the breeding work in 1936, the present writers attempted to gather all of the most important varieties which possessed either resistance to parasites, hardiness, or were of promise in making good winter growth, and to hybridize in an effort to combine all of these characters.

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[1]Research paper No. 655, Journal Series, University of Arkansas, Fayetteville, Ark. Received for publication October 6, 1939. Published with the approval of the Director of the Arkansas Agricultural Experiment Station.

[2]Professor of Plant Pathology, Instructor of Plant Pathology, and Assistant Professor of Agronomy, respectively.

[3]Stanton, T. R., Murphy, H. C., Coffman, F. A., and Humphrey, H. B. Development of oats resistant to smuts and rusts. Phytopath., 24:165–167. 1934.

To N. I. Hancock and C. B. Cross and particularly to T. R. Stanton, H. C. Murphy, and C. R. Adair, the writers are very greatly indebted for furnishing seeds of their own valuable selections and hybrids, none of which were on the market and some of which had not been described. The generosity of these investigators made it possible to bring together probably the most promising group of oats that has been available up to the present, particularly from the standpoint of breeding to combine resistance to parasitic diseases with winter growth and hardiness. Without their cooperation, no such breeding could have been possible.

The paradox of attempting to combine hardiness with winter growth seemed rather questionable in the face of a considerable body of evidence indicating a lack of or reduction in hardiness when plants are in a growing condition. Nevertheless, since hardiness under Arkansas conditions requires a plant capable of growing under relatively mild winter temperatures interspersed between sharp drops of short duration, it appeared desirable to attempt such a combination.

Working in a greenhouse during the winter of 1936–37, the writers emasculated and pollinated 6,045 oat florets and obtained 984 seeds. Approximately one-third of these seeds failed to germinate, but over 600 F_1 hybrids were grown with sufficient seeds obtained from each plant to enable planting in most instances several rod rows outdoors in the fall, and also some in the greenhouse. All of the seeds from the F_1 plants were artificially inoculated with loose and covered smut of oats. The F_2 plants grown in the greenhouse were artificially inoculated with race 1, the most common and destructive race of crown rust found in Arkansas. All plants found susceptible to either crown rust or smut were discarded, and seeds were saved from the remaining plants.

In the field, several thousand F_2 plants survived the winter of 1937–38. Since check plantings of standard varieties and of hardy parents space-planted as were the hybrids, suffered very marked reduction in stand during this winter, some with a complete killing of all the plants, it appeared that the surviving hybrids possessed hardiness. The crown rust resistant varieties Bond and Victoria were completely killed, while all of the strains of Red Rustproof included in the tests showed very marked reduction in stand. Ferguson 922, for example, was reduced to a stand of 6.5%. Subsequent hardiness tests in the F_3 generation suggest that some of the hybrids possess as much hardiness as the hardiest parents.

The progeny of these hybrids are now in the F_4 and F_5 generations. Field tests during the past year, 1938–39, at the main experiment station at Fayetteville and at the rice branch station at Stuttgart indicate a relatively large number of hybrid selections capable of making one and a half to several times as much winter growth as the original parents or as the best of the commercial varieties. There is also promise that resistance to the diseases designated above has been combined with hardiness and ability to make winter growth. On the other hand, in some of the hybrids there are indications that good grain characters have not been combined with other desirable properties, particularly with good winter growth. This, however, does not

appear to be true for all hybrids. Some of the more promising hybrids consist of the following:

Coker's 32-1 × Victoria and its reciprocal
Coker's 32-1 × (Victoria × Richland) and its reciprocal
Tennessee 1884 × Bond
Tennessee 1884 × (Bond × Iogold)
Tennessee 1922 × Bond
Tennessee 1922 × (Victoria × Richland) and its reciprocal
Tennessee 1922 × (Bond × Iogold)
Tennessee 1922 × (Fulghum × Victoria)
Fulghum 3232 × Bond
Lee × (Victoria × Richland) and its reciprocal
Lee × (Bond × Iogold)
Lee × (Fulghum × Victoria)
Custis × (Bond × Iogold) and its reciprocal
Hairy Culberson × Bond
Hairy Culberson × (Bond × Iogold)
Coker's Fulgrain 33-19 × (Victoria × Richland)
Coker's Fulgrain 33-19 × (Bond × Iogold)
Victoria × Custis
Victoria × Coker's Fulgrain 33-19
(Victoria × Richland) × (Hairy Culberson × Fulghum) Oklahoma 2900
(Victoria × Richland) × Hairy Culberson
(Bond × Iogold) × Coker's 32-1
(Bond × Iogold) × Tennessee 1945
(Fulghum × Victoria) × (Bond × Iogold)
(Hairy Culberson × Fulghum) Oklahoma 2900 × Victoria
(Hairy Culberson × Fulghum) Oklahoma 2900 × (Bond × Iogold)
(Lee × Bond) × Fulghum 3232
(Lee × Bond) × (Fulghum × Victoria)

Some 8,000 individual plant selections from these and other hybrids are now being grown at two stations in Arkansas and seeds from a few of the hybrids have been made available to other investigators. It is quite likely that small quantities of seeds will be available for additional distribution in the summer of 1940. It is to be noted that while some of the hybrids now appear to be homozygous for resistance to rusts and smuts and for winter growth and hardiness, a relatively large number are still segregating. It may also be noted that, while the chief emphasis has been placed on breeding for much-needed winter forage, and that grain characters have also been considered nevertheless no immediate recommendations are possible because of insufficient data. It can be said, however, that some of the hybrids are quite promising.

THE DURATION OF THE EFFECTS OF RENOVATION IN THE CONTROL OF WEEDS AND WHITE GRUBS (*PHYLLOPHAGA* sp.) IN PERMANENT BLUEGRASS PASTURES[1]

F. V. Burcalow, D. W. Smith, and L. F. Graber[2]

The establishment of the dry-weather legumes, sweet clover (*Melilotus alba*, or *Melilotus officinalis*), alfalfa (*Medicago sativa*), and red clover (*Trifolium pratense*), in permanent bluegrass pastures for the purpose of improving them without plowing, has been developed by Graber (1, 2, 3),[3] and is designated as renovation. Papers have also been published by Fuelleman and Graber (4, 5) showing the effectiveness of this method of pasture improvement in the control of weeds and white grubs during periods of 1, 2, and 3 years after the legumes were established. Additional data were gathered in 1939 by the quadrat method which show further duration of the residual benefits of renovation in terms of the reductions in weed and white grub populations, as well as to indicate the principal factors on which the duration of such benefits rest. These studies were made in 1939 on 14 of the 30 permanent bluegrass pastures where portions of from 1 to 33 acres had been renovated in 1934 and 1935, and on which studies of weed and white grub populations were made by Fuelleman and Graber (4, 5) in 1935–36 and 1937.

PREVIOUS STUDIES

In 1937, the total weed populations (5) of the renovated portions of the 30 pastures were 85.8% less than the weed populations of the adjacent areas of unrenovated bluegrass. The populations of white grubs (4) as determined by counts made in 1935–36, were 98% less in the portions of 15 pastures renovated in 1934, and 91% less in the portions of the 15 pastures renovated in 1935, than in adjacent areas of unrenovated bluegrass of equal area.

In 1939, 7 of the 15 pastures where a portion of each was renovated in 1934 and 7 of the 15 pastures where a portion of each was renovated in 1935, were selected on the basis of their distribution in southwestern Wisconsin, for further study of the weed and white grub populations using the same methods of determination.

The weed counts in 1937 and the grub counts in 1935–36 on the renovated and unrenovated portions of these 14 pastures are shown in Tables 1 and 2. As previously indicated, these pastures were studied again in 1939 and in the tabulations, they are divided into two groups. One group of nine pastures was grazed moderately, or cut for hay, or both, and the other group of five pastures was grazed excessively.

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[1]Contribution No. 147 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication October 5, 1939.

[2]Instructor, Assistant, and Professor of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 22.

TABLE 1.—*Total numbers of weeds per acre in the renovated portions of each of 14 pastures renovated in 1934 and 1935 and in adjacent portions of each not renovated.*

Pasture No.	When renovated	No. of weeds per acre on unrenovated and renovated portions					
		1937			1939		
		Not renovated	Renovated	% reduction	Not renovated	Renovated	% reduction
		Grazed Moderately, or Cut for Hay, or Both					
1	June 12, '34	674,000	88,000	86.9	322,000	6,000	98.1
4	June 11, '34	930,000	182,000	80.4	300,000	6,000	98.0
6	May 4, '34	716,000	58,000	91.9	286,000	50,000	82.5
7	May 17, '34	994,000	54,000	94.6	964,000	146,000	84.9
10	May 8, '34	1,478,000	374,000	74.7	632,000	16,000	97.5
16	June 1, '35	1,876,000	448,000	76.1	304,000	28,000	90.8
18	May 9, '35	994,000	290,000	70.8	182,000	8,000	95.6
20	May 25, '35	928,000	322,000	65.3	832,000	30,000	96.4
23	May 21, '35	652,000	44,000	93.3	68,000	2,000	97.1
Average		1,026,889	206,667	79.9	432,222	32,444	92.5
		Grazed Excessively					
5	May 28, '34	1,316,000	108,000	91.8	238,000	98,000	58.8
12	May 3, '34	702,000	110,000	84.3	46,000	24,000	47.8
19	June 7, '35	510,000	110,000	78.4	432,000	122,000	71.8
21	May 16, '35	1,264,000	158,000	87.5	250,000	180,000	28.0
28	Mar. 20, '35	1,408,000	54,000	96.2	282,000	152,000	46.1
Average		1,040,000	108,000	89.6	249,600	115,200	53.8

In the nine pastures grazed moderately, or cut for hay, or both, renovation reduced the weed populations 79.9% in 1937 and the white grub populations 98.3% in 1935–36. In the five pastures grazed excessively, renovation reduced the populations of weeds 89.6% in 1937 and of white grubs 95.8% in 1935–36. In 1939, however, the residual benefits of the renovations of 1934 and 1935 as measured on the basis of the control of the two common pests of the permanent grasslands of Wisconsin was dependent primarily on the managerial treatments of the renovated and unrenovated portions of each pasture.

RESIDUAL BENEFITS IN 1939 FROM 14 RENOVATIONS OF 1934 AND 1935

Where moderate grazing was practiced on the unrenovated portions of nine pastures and where the adjacent renovated areas were grazed moderately, or cut for hay, or both, in the years following the establishment of the legumes, the renovations of 1934 and 1935

(Tables 1 and 2) reduced the weed populations in 1939, 92.5% and the white grub populations 75.2%.

TABLE 2.—*Total numbers of white grubs per acre in the renovated portions of each of 14 bluegrass pastures renovated in 1934 and 1935 and in adjacent portions of each not renovated.*

Pasture No.	When renovated	1935–36			1939		
		Not renovated	Renovated	% reduction	Not renovated	Renovated	% reduction
		Grazed Moderately, or Cut for Hay, or Both					
1	June 12, '34	55,757	0	100.0	62,000	2,000	96.8
4	June 11, '34	34,848	0	100.0	62,000	2,000	96.8
6	May 4, '34	142,000	0	100.0	118,000	42,000	64.4
7	May 17, '34	232,000	0	100.0	126,000	60,000	52.4
10	May 8, '34	292,000	4,000	98.6	160,000	2,000	98.8
16	June 1, '35	172,008	4,356	97.5	82,000	26,000	68.3
18	May 9, '35	214,000	8,000	96.3	232,000	34,000	85.3
20	May 25, '35	128,000	8,000	93.8	52,000	28,000	46.2
23	May 21, '35	154,000	0	100.0	148,000	62,000	58.1
Average		158,290	2,706	98.3	115,778	28,667	75.2
		Grazed Excessively					
5	May 28, '34	220,000	8,000	96.4	158,000	86,000	45.6
12	May 3, '34	0	0	0	78,000	62,000	20.5
19	June 7, '35	120,000	14,000	88.3	42,000	22,000	47.6
21	May 16, '35	330,000	8,000	97.6	182,000	28,000	84.6
28	Mar. 20, '35	156,700	4,356	97.2	86,000	30,000	65.1
Average		165,340	6,871	95.8	109,200	45,600	58.2

Where excessive grazing was practiced on both the renovated and adjacent unrenovated areas of five pastures, the renovations of 1934 and 1935 reduced the weed populations in 1939, 53.8% and the white grubs 58.2%. It is obvious that without judicious managerial treatments, the duration and efficiency of renovation in the improvement of bluegrass pastures is greatly curtailed.

Weeds were much less prevalent in the bluegrass pastures of southern and western Wisconsin in 1939 than in 1937. This was shown by general observations and is illustrated more specifically by the total populations (Table 1) in the unrenovated portions of the 14 pastures which were studied. They averaged over one million weeds per acre in 1937 when ragweeds (*Ambrosia artemisiifolia*) and horseweeds (*Erigeron canadensis*) were the dominant species, compared with less than a half-million in 1939 when ragweeds, as usual, were the dominant species.

With moderate grazing, the renovations were more effective in reducing weeds (92.5%) in 1939 than in 1937 when the reduction was 79 9%, but with excessive grazing the control of weeds in 1939 by the renovations of 1934 and 1935 was much less (89.6% in 1937 compared with 53.8% in 1939). Excessive grazing up to and including 1937 enhanced to some extent the degree of weed control (89.6%) resulting from the renovations when compared with moderate grazing (79.9%), but when excessive grazing was continued up to and including 1939, weed control was severely reduced.

While all the renovations resulted in a very high degree of white grub control (over 95%) in 1935-36 (Table 2), such control was reduced to 75.2% in 1939 under the managements designated as moderate grazing, or cut for hay, or both, and to 58.2% with excessive grazing. Managerial treatments had much to do with the duration of maximum benefits from renovations in white grub control. Because fewer dry-weather legumes prevailed in the renovated areas to repel the egg-laying June beetles in 1937 and 1938 than during the beetle flights three years previous (1934 and 1935), grub control in 1939 was to a very considerable extent due to the greater density of the sod of the renovated areas. In general, the densities of the grass sods were inversely correlated with the intensities of grazing.

VARIABILITY OF DATA

A comparison of the data (Tables 1 and 2) showing the degree and duration of the benefits of renovation in terms of weed and white grub control in each of the 14 pastures studied reveals a wide variability. Thus, the reduction of weeds in the five pastures grazed excessively varied from 28.0% (pasture No. 21) to 71.8% (pasture No. 19) in 1939. Likewise, the variability in white grub control ranged from 20.5% (pasture No. 12) to 84.6% (pasture No. 21) in 1939.

Since the 14 pastures were widely distributed in southern and western Wisconsin, and since the renovations were established on soils which differed widely in type, exposure, and fertility, and since a wide range in the amount of rainfall and other climatic factors prevailed, variability is to be expected. The averages are used merely to simplify the presentation and discussion of the data.

MANAGERIAL TREATMENTS

All the unrenovated portions of the 14 pastures under consideration were grazed annually with cattle. Most of the renovated portions were also grazed with the cattle, and in nearly all such instances the same cattle had "free choice" in the grazing of the renovated and unrenovated portions of each pasture. Invariably the cattle showed a definite preference for the grasses and legumes of the renovated portion and this was true particularly in the dry portions of the grazing season.

The legumes utilized for the renovations, and the grazing and cutting treatments following the year in which the legumes were established, are shown in Table 3. The nine renovations cut for hay, or used for hay and pasture, or grazed moderately, are placed in a group

in Tables 1 and 2 for the reason that the managerial practices applied to them and the adjacent areas not renovated were of such a character as not to weaken the grasses (predominately bluegrass) by lowering the food reserves, or otherwise. In contrast, the grasses of the five pastures grouped in Tables 1 and 2 as being grazed excessively were weakened by reductions in food reserves from the close early spring grazing and heavy pasturing throughout the entire growing season.

TABLE 3.—*Legumes established in the renovated portions of 14 permanent bluegrass pastures and the managerial treatments of the renovated areas following the year in which the legumes were sown.*

Pasture No.	When renovated	Legumes established*	Managerial treatments of renovated portions*				
			1935	1936	1937	1938	1939
1	June 12, '34	Alf., R. C.	Hay	Hay	H. & P.	H. & P.	H. & P.
4	June 11, '34	Alf., R. C.	Hay	Hay	Hay	Mod. gr.	Mod. gr.
6	May 4, '34	Sw. Cl.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
7	May 17, '34	Sw. Cl.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
10	May 8, '34	Alf., R. C., Sw. Cl.	Hay	Hay	Mod. gr.	Mod. gr.	Mod. gr.
16	June 1, '35	Alf., Sw. Cl.	———	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
18	May 9, '35	Sw. Cl.	———	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
20	May 25, '35	Sw. Cl.	———	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
23	May 21, '35	R. C., Alf.	———	H. & P.	H. & P.	H. & P.	H. & P.
5	May 28, '34	Alf., Sw. Cl.	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
12	May 3, '34	Alf., Sw. Cl.	H. & P.	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
19	June 7, '35	Alf., Sw. Cl.	———	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
21	May 16, '35	Sw. Cl.	———	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
28	Mar. 20, '35	Sw. Cl.	———	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.

*Alf. = Alfalfa; R. C. = Red clover; Sw Cl. = Sweet clover (biennial white); H. and P. = Hay and pasture; Mod. gr. = Moderate grazing; and Ex. gr. = Excessive grazing.

PERSISTENCE OF LEGUMES IN RENOVATED AREAS

A fairly good stand of alfalfa still prevailed in 1939 in the renovated portions of pastures Nos. 1 and 4 which had been cut for hay and grazed moderately, and a good stand of red clover persisted (by virtue of reseeding) in the renovated portion of pasture No. 23. A very good stand of seedling plants of biennial white blossom sweet clover prevailed (1939) in the renovated portions of pastures Nos. 6, 16, 18, 20, and 28, and likewise, a fairly good stand of young sweet clover and old alfalfa prevailed in the renovated portion of pasture No. 10. All but two of the pastures (Nos. 19 and 28) grazed excessively were devoid of the dry-weather legumes in 1939 which had been sown in the renovations of 1934 and 1935. A surprisingly good stand of seedling plants of sweet clover prevailed in the renovated area of pasture No. 19 and a fair stand in pasture No. 28. Alfalfa did not persist effectively after its establishment for more than 2 years under excessive grazing treatment.

The extent to which sweet clover which had been grazed so as to produce seed in its second year was able to re-establish itself depended

largely on a desirable content of lime, phosphate, and potash in the soil and on the density of the grass sods. The latter was greatly influenced by the grazing treatments, water retention of the soil, and nitrogen content.

MANAGEMENT AND PERSISTENCE OF SWEET CLOVER

Where sweet clover is grazed heavily for two or three weeks in early spring of its second year's growth and then allowed to recover and approach blossoming before grazing is resumed, much seed is usually formed despite moderately heavy grazing. If, after such seed formation very close grazing of the grasses is practiced for the remainder of the season, the grasses are weakened and their competition is sufficiently reduced, as a rule, to permit seedling plants to establish themselves the following spring. At times, the grasses of the renovated areas are again grazed closely the following spring before the sweet clover seedlings attain sufficient height to be injured by defoliation. Trampling is not very injurious unless the soil is well saturated with moisture. However, such early spring grazing can only be temporary, otherwise the seedling plants of sweet clover may be destroyed.

After about July 15 (in Wisconsin) when the seedling plants are well established, moderate grazing up to September 1, or thereabouts, is practiced without severe injury to the stand of young sweet clover. For the fall period, the plants are unmolested so that they can elaborate and store foods for the development of hardy rhizomes and for the survival of the over-wintering parts.

This method of grazing was not always practiced with respect to the renovations on which results are reported in this paper. However, where sweet clover reseeded itself abundantly the year after sowing and where the grass sods did not become too dense, the appearance of young sweet clover plants prevailed for one or more years in many of the renovations where sweet clover was sown.

Farmers are fast becoming cognizant of the economy in the utilization of sweet clover for pasture improvement. The soil is enriched with nitrogen and organic matter. Weeds and white grubs are greatly reduced, not only for the first two years after the renovation treatment, but in subsequent years as well. With judicious grazing and proper soil conditions, good stands of sweet clover may prevail for several years by virtue of reseeding. Of the three dry-weather legumes, sweet clover was by far the most aggressive in re-establishing itself by reseeding. Medium red clover was intermediate in this respect, but the reseeding of alfalfa was practically nil in these trials.

A RENOVATION IN 1929

The first outlying demonstration of pasture renovation in Wisconsin was established in 1929 with sweet clover on four acres of a steep hillside pasture located in southwestern Wisconsin near Mineral Point. The soil was in a low state of fertility. Ragweeds (*Ambrosia artemisiifolia*) and wild carrot (*Daucus carota*) were abundant in this pasture and the grasses were mostly Kentucky bluegrass and Canadian bluegrass. With applications of lime, phosphate, and potash, and

with proper scarification by disking and harrowing of the thin sod, and other desirable cultural treatments in 1929 (grazing was completely eliminated), an excellent stand of biennial white blossomed sweet clover was established. In 1930, this sweet clover and the grasses associated with it were grazed closely from May 10 to June 21. The cattle were removed on the latter date and grazing was not resumed until July 21, when the second growth of the sweet clover was fully 4 feet high and well blossomed. Although the sweet clover and grasses were grazed heavily from July 21 to November 1, a very heavy set of seed occurred in August and nearly all of it had fallen to the soil before winter. From 1931 to 1939, inclusive, the fence around the renovated portion was removed and the cattle had "free choice" as far as the grazing was concerned. Because they preferred the grasses and sweet clover of the renovated portion, it received more intensive grazing than the unrenovated portion of the pasture.

In southwestern Wisconsin the major flights (broods C and A) of egg-laying June beetles occurred in 1928 and 1929, 1931 and 1932, 1934 and 1935, and in 1937 and 1938. The years of severe damage from white grubs occurred in 1930, 1933, 1936, and 1939. In 1930, 220,000 white grubs per acre were found on the unrenovated portion of this pasture and only 20,000 on the renovated portion, a reduction of 90.9%. In 1933, this renovation continued to reduce grub populations from 180,000 to 23,000, or 87.2%; in 1936 from 118,000 to 24,000, or 79.7%; and in 1939, from 142,000 to 42,000, or 70.4%.

Weed counts were taken only in 1937, 1938, and 1939 when the total populations per acre were 2,554,000, 942,000, and 232,000 respectively, on the unrenovated portion compared with 162,000, 94,000, and 50,000 respectively, on the renovated portions. The reductions in weed populations were 93.7%, 90.0%, and 78.5%, respectively. The benefits from the renovation of 1929, as measured in terms of weed and white grub control, persisted to a very marked degree for a period of 10 years and this was largely due to conditions which made it possible for sweet clover to maintain itself effectively by reseeding in 1930 and re-establishment in 1931 and thereafter. New and dense stands of young seedling plants of sweet clover appeared in 1931, 1932, 1933, and in 1935, and they were grazed in such a manner as to assure a fairly good survival and dense second-year growths in 1932, 1934, and 1936. However, the sod became so dense after 1936 that the reseeding and the re-establishment of the sweet clover was greatly reduced.

Among the interesting vegetational changes which followed this renovation of 1929 was the disappearance of Canadian bluegrass (*Poa compressa*) and of wild carrot (*Daucus carota*) in the renovated portions of the pasture.

SUMMARY

The establishment of dry-weather legumes in permanent bluegrass pastures without plowing and without destroying the grasses is designated as renovation. While for the first two or three years after renovation, such treatment was very effective in controlling weeds and white grubs (*Phyllophaga* sp.), the two common pests of permanent

grasslands in southern and western Wisconsin, further duration of such benefits was dependent on managerial treatment. With moderate grazing or its equivalent, weeds were reduced 92.5% and white grubs 75.2% in 1939 on the portions of nine pastures renovated in 1934 and 1935, when compared with adjacent unrenovated portions of equal area. With excessive grazing on five pastures such weed reductions averaged 53.8% and the white grub control was only 58.2% in 1939.

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TOXIC LIMITS OF REPLACEABLE ZINC TO CORN AND COWPEAS GROWN ON THREE FLORIDA SOILS[1]

O. E. GALL AND R. M. BARNETTE[2]

THE practical use of zinc compounds for the prevention and correction of the malnutrition of a number of plants growing under a variety of soil conditions has been reported during the past decade. In Florida, Allison (1),[3] Allison, Bryan, and Hunter (2), and Allison and Hunter (3) obtained responses to zinc with corn, peanuts, and many other crops grown in the raw peat soils of the Everglades. Mowry (13) and Mowry and Camp (14) found that "bronzing" of tung trees, a malnutrition of *Aleurites fordii* and related species growing in the mineral soils of central, north, and northwest Florida, was due to a deficiency of available zinc in these soils. Also, Blackmon (7) reported the beneficial effects of zinc sulfate for the correction and prevention of "rosette" of pecans and the malnutrition of related nut species growing on mineral soils in the same area.

Barnette and Warner (4) and Barnette, *et al.* (5) reported the use of zinc sulfate for the prevention of "white bud" of corn as well as the malnutrition of velvet beans, cowpeas, millet, and other agronomic crops grown on the mineral soils of Florida. Camp (9) extended the use of zinc sulfate, mostly in the form of a zinc spray, for the correction of "frenching" of citrus trees. "Frenching" of citrus trees occurs both where there is an excess of lime in the soil and in excessively leached, acid soils. Likewise, Townsend (16) found the lack of zinc a cause for failure of beans grown on the newly cleared sawgrass soils at some distance from Lake Okeechobee in the Everglades.

In all the experiments reporting a beneficial effect of zinc, either added to the soil or used as a spray, the quantities added have been relatively small. Thus, 89% zinc sulfate was effective in preventing or correcting the malnutrition of a number of plants when applied at the rate of 5 to 20 pounds per acre in the row for agronomic crops, or ½ to 1 pound per tree (30 to 60 pounds per acre) for tree crops and even smaller quantities were sufficient when added in the form of sprays. On the other hand, the toxicity of zinc to plant growth has been abundantly proved, especially in water cultures, making it highly desirable to develop information as to the limits of toxicity of zinc under different soil conditions and for various plants. It is also of value to know methods of alleviating this toxicity.

In this connection, Freytag (11) in 1868 established that zinc replaced or rendered soluble other cations in the soil, including calcium, magnesium, potassium, and sodium. Baumann (6) attributed the great divergence of the toxic limits of zinc obtained by different work-

[1]Contribution from the Department of Chemistry and Soils, University of Florida, Agricultural Experiment Station, Gainesville, Fla. Received for publication October 13, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 31.

ers to the wide variations in the fixing power of soils. Thus, a much lower concentration of zinc was toxic in sandy soils than in humus and marl soils. Brenchley (8) concluded from a review of results reported by many workers that insoluble zinc compounds, such as the oxide, carbonate, phosphate, and sulfide, are seldom toxic to plant growth, while the toxic character of soluble zinc compounds at relatively low concentrations in water cultures, sand cultures, and soils with low fixing power has often been shown.

Recently, Jones, *et al.* (12) studied the reaction of zinc sulfate with the soil and concluded that there are three classes of compounds formed, namely, (a) water-soluble zinc compounds, (b) combinations of zinc with the colloidal portion of the soil (replaceable zinc), and (c) water-insoluble and non-replaceable zinc combinations, such as carbonates, phosphates, and other complex compounds. Replaceable zinc may be considered just as active as other replaceable cations in the soil and also toxic to plant growth under certain conditions. For this reason the toxic limits of replaceable zinc rather than that of water-soluble and total zinc have been studied.

EXPERIMENTAL PROCEDURE

The surface soils of a Norfolk sand, an Orangeburg fine sandy loam, and a Greenville clay loam were used for plant studies in the greenhouse. A quantity of each of these soils was air-dried in thin layers in the greenhouse, screened through a 2-mm, round-hole sieve, and thoroughly mixed.

The procedure for establishing the cultures was the same as that used by Jones, *et al.* (12). A portion of each of the screened surface soils was placed in 3-gallon coffee urn pots and treated with a concentrated zinc sulfate solution. Additional water was added to insure a contact of the zinc sulfate with all the soil. After standing in this condition for a week all salts in free solution were washed out of the soils with distilled water. Frequent tests for sulfate were made in the leachates and the washing discontinued when a negative test was obtained. Then the soils were again spread in thin layers and air-dried in the greenhouse.

The soils treated in this manner were practically saturated with replaceable zinc. The replaceable zinc contents of the three types were 1.376, 1.896, and 2.692 M.E. per 100 grams of air-dried soil[4] for the Norfolk sand, Orangeburg fine sandy loam and Greenville clay loam, respectively. Replaceable zinc was determined by the method of Cone and Cady (10) as modified by Jones, *et al.* (12).

Small glazed earthenware pots holding 1,200 grams of soil were used for the study of the toxicity of replaceable zinc. Cultures with a range of concentration of replaceable zinc were established by combining different proportions of the untreated and zinc-saturated soils. The soils were fertilized with chemically pure salts as indicated in the tables. Duplicate cultures were established for each of the soil treatments used. Corn and cowpeas were used as test plants. Ten seed of Whatley's prolific corn and of Suwannee cowpeas were planted in each of the pots. Upon germination and establishment of the seedlings, they were thinned to a uniform stand of five plants in each culture. Visually optimum moisture conditions for plant growth were maintained by frequent weighings and additions of dis-

[4]The factor for changing milliequivalents of zinc per 100 grams of soil to pounds per acre is 654, i.e., 654×M.E. of zinc per 100 grams of soil = pounds of zinc per acre.

tilled water. Each planting of corn or cowpeas was grown for approximately one month. The plants in each pot were harvested by severing the tops from the roots at the soil level. The plants were dried at 100° C. The roots were removed from the soil in the pots before another crop was planted.

EXPERIMENTAL RESULTS

Two crops of corn and two of cowpeas were grown in rotation in each of the soils used for the experiment.

The average relative weights of the corn and cowpeas were calculated on the basis of the average dry weights of plants grown in cultures without zinc treatment and fertilized with ammonium nitrate only. The results of these calculations for corn and cowpeas are given in Tables 1 and 2, respectively.

The results obtained with corn indicate that replaceable zinc is definitely toxic to plant growth at a concentration between 0.688 and 1.376 M.E. per 100 grams of air-dried Norfolk sand. The lower limit of this range of replaceable zinc was slightly toxic while the higher limit was definitely toxic. The use of 233 pounds per acre of mono-calcium phosphate did not significantly influence this range, though 1,000 pounds per acre of calcium carbonate reduced the toxicity of replaceable zinc in the culture containing 1.376 M.E. of replaceable zinc from 32% of the growth with no added replaceable zinc in the ammonium nitrate cultures to 63% in the ammonium nitrate cultures with calcium carbonate.

Lott (15) has recently shown that by lowering the hydrogen-ion concentration with additions of calcium carbonate, zinc toxicity is alleviated. It is noted that in the presence of either mono-calcium phosphate or calcium carbonate a considerable amount of replaceable zinc (0.206 M.E. or 135 pounds zinc per acre), causes a stimulation in plant growth. Unfortunately, the Norfolk sand cultures were not established so as to give a range suitable for determining more exactly the toxic limits at the higher concentrations of replaceable zinc.

The results obtained with corn at different concentrations of replaceable zinc in the Orangeburg fine sandy loam indicate that 0.758 to 1.137 M.E. of replaceable zinc per 100 grams of air-dried soil were toxic in the series of cultures with ammonium nitrate alone; the series with 1,800 pounds mono-calcium phosphate in addition showed the same range of toxicity. On the other hand, with additions of ammonium nitrate plus 4,000 pounds per acre of calcium carbonate, toxicity was shown to be within the range of 1.137 and 1.516 M.E. of replaceable zinc per 100 grams of soil. Also, with the highest concentration of 1.896 M.E. of replaceable zinc per 100 grams of air-dried soil, the 4,000 pounds per acre application of calcium carbonate decreased the toxicity to corn by an increased yield that varied from 32% without the carbonate to 61% with the carbonate. In this soil type a positive response of corn to the application of mono-calcium phosphate was noted with the lower concentrations of replaceable zinc.

The nature of these experiments precludes the determination of a definite concentration of replaceable zinc which will be toxic to the plants. For this reason a range of concentration within which the re-

TABLE 1.—*The effect of increasing quantities of replaceable zinc in the soil on the growth of corn.*

Applications of fertilizing salts per acre	Relative yields of corn								
	Norfolk sand								
	0.000	0.069*	0.138	0.206	0.275	0.482	0.688	1.376	
100 lbs NH_4NO_3	100 (0.89 gram)†	95	92	89	96	93	85	32	
100 lbs. NH_4NO_3 and 233 lbs. $CaH_4(PO_4)_2$	92	98	99	113	105	95	96	34	
100 lbs. NH_4NO_3 and 1,000 lbs. $CaCO_3$	90	97	99	103	96	95	93	63	
	Orangeburg fine sandy loam								
	0.000	0.047*	0.095	0.189	0.379	0.758	1.137	1.516	1.896
150 lbs. NH_4NO_3	100 (0.87 gram)†	101	87	94	93	81	62	56	32
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	131	125	127	134	120	98	65	62	37
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	104	87	93	98	98	86	83	73	61
	Greenville clay loam								
	0.000	0.067*	0.134	0.269	0.538	1.077	1.615	2.153	2.692
150 lbs. NH_4NO_3	100 (0.91 gram)†	108	116	121	116	100	88	67	42
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	148	138	143	151	128	115	89	63	42
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	123	115	109	108	105	109	100	84	70

*M.E. of replaceable zinc per 100 grams of air-dried soil. For converting M.E. per 100 grams soil to pounds of zinc per acre multiply by 654.
†Average oven-dried weights of plants grown with ammonium nitrate without addition of replaceable zinc used as a basis for calculation of all relative yields.

TABLE 2.—*The effect of increasing quantities of replaceable zinc in the soil on the growth of cowpeas.*

Applications of fertilizing salts per acre	Relative yield of cowpeas								
	Norfolk sand								
	0.000	0.069*	0.138	0.206	0.275	0.482	0.688	1.376	
100 lbs. NH_4NO_3	100 (0.99 gram)†	96	91	86	92	71	61	25	
100 lbs. NH_4NO_3 and 233 lbs. $CaH_4(PO_4)_2$	99	96	90	82	94	74	61	35	
100 lbs. NH_4NO_3 and 1,000 lbs. $CaCO_3$	120	104	104	94	96	94	72	52	
	Orangeburg fine sandy loam								
	0.000	0.047*	0.095	0.189	0.379	0.758	1.137	1.516	1.896
150 lbs. NH_4NO_3	100 (1.5 gram)†	114	113	106	91	54	22	16	12
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	112	118	113	117	93	71	26	13	14
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	101	98	109	111	100	103	93	90	74
	Greenville clay loam								
	0.00	0.067*	0.134	0.269	0.538	1.077	1.615	2.153	2.692
150 lbs. NH_4NO_3	100 (1.27 gram)†	95	101	93	92	72	36	21	17
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	112	106	111	131	99	59	30	22	14
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	118	96	116	107	91	93	71	50	34

*M.E. of replaceable zinc per 100 grams of air-dried soil. For converting M.E. per 100 grams of soil to pounds per acre multiply by 654.

†Average oven-dried weights of plants grown with ammonium nitrate without addition of replaceable zinc used as a basis for calculation of all relative yields.

placeable zinc may begin to be toxic has been used. The higher limits of this range have been set at the concentration of replaceable zinc which will decrease the plant yields at least 25%. Logically the lower limits become the next lower concentration.

The Greenville clay loam showed that the amounts of replaceable zinc toxic to corn in the series with 150 pounds of ammonium nitrate alone were between 1.615 and 2.153 M.E. per 100 grams of air-dried soil. The same limits were observed for the series with ammonium nitrate plus mono-calcium phosphate. On the other hand, the toxic limits for the series of cultures treated with ammonium nitrate plus calcium carbonate were between 2.153 and 2.692 M.E. of replaceable zinc per 100 grams of air-dried soil. In addition to these observations, a definite increase in yields of corn plants with the application of mono-calcium phosphate to Greenville clay loam was noted with the cultures having the lower concentrations of replaceable zinc. The lower concentrations of replaceable zinc stimulated plant growth in the cultures with ammonium nitrate alone as well as in those with ammonium nitrate plus calcium carbonate.

The toxic limits of replaceable zinc for cowpeas were observed to be distinctly lower than for corn (Table 3). In the Norfolk sand cultures, the toxic limit for cowpeas was between 0.275 and 0.482 M.E. of replaceable zinc per 100 grams of soil in the ammonium nitrate and in the combination ammonium nitrate and mono-calcium phosphate treatments. On the other hand, the limits for the ammonium nitrate-calcium carbonate cultures were between 0.482 and 0.688 M.E. per 100 grams. Likewise, the carbonate increased the plant growth through the entire range of replaceable zinc concentrations.

TABLE 3.—*The toxic range of replaceable zinc for corn and cowpeas.*

Applications of fertilizing salts, per acre	M. E. of replaceable zinc per 100 grams of air-dried soil toxic to	
	Corn	Cowpeas
Norfolk Sand		
100 lbs. NH_4NO_3	0.688–1.376	0.275–0.482
100 lbs. NH_4NO_3 and 233 lbs. $CaH_4(PO_4)_2$	0.688–1.376	0.275–0.482
100 lbs. NH_4NO_3 and 1,000 lbs. $CaCO_3$	0.688–1.376	0.482–0.688
Orangeburg Fine Sandy Loam		
150 lbs. NH_4NO_3	0.758–1.137	0.379–0.758
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	0.758–1.137	0.379–0.758
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	1.137–1.516	1.516–1.896
Greenville Clay Loam		
150 lbs. NH_4NO_3	1.615–2.153	0.538–1.077
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	1.615–2.153	0.538–1.077
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	2.153–2.692	1.077–1.615

The toxic limit of replaceable zinc for cowpeas in the Orangeburg fine sandy loam was between 0.379 and 0.758 M.E. for the cultures receiving ammonium nitrate alone as well as those receiving both

ammonium nitrate and mono-calcium phosphate. However, the addition of phosphate stimulated the growth of the cowpeas in the lower zinc applications. The toxic limit of concentration was increased to between 1.516 and 1.896 M.E. of replaceable zinc per 100 grams by an application of 4,000 pounds per acre of calcium carbonate. The toxicity in the cultures with 1.896 M.E. of replaceable zinc per 100 grams of air-dried soil was very materially reduced by the calcium carbonate.

With the Greenville clay loam a concentration somewhere between 0.538 and 1.077 M.E. of replaceable zinc per 100 grams of soil proved toxic to cowpeas in the cultures with ammonium nitrate and mono-calcium phosphate, while the range for the cultures receiving calcium carbonate was between 1.077 and 1.615 M.E. Both treatments receiving mono-calcium phosphate and calcium carbonate, respectively, showed stimulated growth with the lower concentrations of replaceable zinc.

The toxic limits of replaceable zinc for corn and cowpeas grown in a Norfolk sand, an Orangeburg fine sandy loam, and a Greenville clay loam with ammonium nitrate, ammonium nitrate plus mono-calcium phosphate, and ammonium nitrate and calcium carbonate are summarized in Table 3. The results indicate that in the Norfolk soil the point of toxic limit to plants falls nearer the lower than the upper limits of the ranges used.

The quantities of replaceable zinc necessary to be toxic to corn increased with an increase in the total replaceable zinc content of the soils. In other words, the toxic limits were raised with an increase in the quantity of replaceable zinc held in the soil, being at a lower range in Norfolk sand and increasing in the Orangeburg fine sandy loam and Greenville clay loam. Mono-calcium phosphate did not change these ranges. Calcium carbonate, however, materially increased the quantity of replaceable zinc necessary to be toxic to corn.

The germination of corn was not decreased by replaceable zinc but growth was slow above toxic concentrations. At these concentrations, the leaves turned yellow between the veins, while the veins themselves remained intensely green. The rate of growth in these cultures was greatly reduced and the plants remained small in comparison with the other cultures where zinc was not present in toxic concentrations.

In the absence of calcium carbonate the toxic concentrations of zinc were very much lower for cowpeas than for corn. Under these conditions of treatment the point of toxic concentration for the Norfolk sand fell somewhere in the concentration range of 0.275 to 0.482 M.E. of replaceable zinc per 100 grams of air-dried soil, that for the Orangeburg fine sandy loam between 0.379 and 0.758 M.E., and that for Greenville clay loam between 0.538 and 1.077 M.E., respectively. It is thus seen that definitely larger quantities of replaceable zinc were required to produce toxic effects on cowpeas in the heavier soils than on the lighter types. Calcium carbonate increased the amount of replaceable zinc necessary to cause toxicity in all three types. This shows the effect of calcium carbonate in overcoming, or at least alleviating, the toxic properties of large quantities of replaceable zinc.

Cowpea seedlings were severely stunted by toxic concentrations of replaceable zinc. Examination of the roots at the toxic concentrations of the three soils showed that nodulation had been decreased at the lower limits of toxicity and prohibited at the higher limits. The germination was not affected by the toxic concentrations of replaceable zinc but growth was slow with the formation of only two to four leaves. These stunted plants remained green until the edges of the leaves began to curl and die. Just before harvest, part of the dead leaves dropped from the stunted plants, but the plants remained alive until harvest.

A series of such cultures grown in the Orangeburg fine sandy loam with various quantities of replaceable zinc, with and without calcium carbonate, are shown in Fig. 1. The beneficial effects of calcium carbonate in preventing the extreme toxicity may be noted.

SUMMARY

Soluble zinc compounds are used under a variety of conditions in Florida to prevent or correct malnutrition of a number of plants caused by a deficiency of available zinc. The zinc accumulates in the

FIG. 1.—The effect of replaceable zinc on the growth of Suwanee cowpeas in Orangeburg fine sandy loam.

M.E. replaceable zinc per 100 grams of soil	Replaceable zinc and ammonium nitrate, pot No.	Replaceable zinc, ammonium nitrate, and 4,000 lbs. per acre $CaCO_3$ pot No.
None	55	91
0.095	59	95
0.379	63	99
1.137	67	103
1.896	71	107

soil either in the mobile replaceable form or in definite water-insoluble forms. The former is known to be toxic to plant growth when it accumulates in sufficient quantities; the latter are seldom toxic to plant growth. In order to establish the toxic limits of zinc for certain plants and to determine methods of preventing or alleviating this toxicity, three series of greenhouse cultures were employed.

A simple but expedient method is described for preparing greenhouse cultures for the above purpose with a Norfolk sand, an Orangeburg fine sandy loam, and a Greenville clay loam, giving ranges of replaceable zinc in the soils. The principal feature of the technic is the use of soils which had been previously saturated with replaceable zinc and washed free from soluble salts, combined in varying proportions with the corresponding air-dried untreated soils to give a suitable range in concentration of replaceable zinc in each soil.

Two crops of corn and cowpeas as test plants were grown for four weeks each in rotation. The weight of the dry plants from each culture was obtained. The results of the tests may be summarized as follows:

1. Replaceable zinc became toxic to corn on a Norfolk sand between the concentrations of 0.688 and 1.376 M.E. per 100 grams (451–902 pounds Zn per acre); between 0.758 and 1.137 M.E. (497–734 pounds Zn per acre) on an Orangeburg fine sandy loam; and between 1.615 and 2.153 M.E. (1,051–1,402 pounds Zn per acre) on a Greenville clay loam.

2. Replaceable zinc became toxic to cowpeas between the concentrations of 0.275 and 0.482 M.E. per 100 grams (181–316 pounds Zn per acre) on a Norfolk sand; between 0.379 and 0.758 M.E. (246–479 pounds Zn per acre) on an Orangeburg fine sandy loam; and between 0.538 and 1.077 M.E. (351–701 pounds per acre) on a Greenville clay loam.

3. The application of mono-calcium phosphate at the rate of 233 pounds per acre to the Norfolk sand and 1,800 pounds per acre to the Orangeburg fine sandy loam and the Greenville clay loam did not change the toxic limits of the replaceable zinc for corn or cowpeas. The presence of phosphate as a plant nutrient, however, stimulated the growth of corn and cowpeas on the Orangeburg fine sandy loam and the Greenville clay loam, while no effect was noted on the Norfolk sand.

4. The use of calcium carbonate at the rate of 1,000 pounds per acre on the Norfolk sand and 4,000 pounds per acre on the Orangeburg fine sandy loam and the Greenville clay loam definitely increased the concentrations at which replaceable zinc became injurious to corn and cowpeas and greatly alleviated the toxic condition.

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THE GERMINATION OF SEED OF *ORYZOPSIS HYMENOIDES*[1]

VIVIAN K. TOOLE[2]

BECAUSE of the difficulty encountered in obtaining satisfactory field stands and laboratory germination of seed of *Oryzopsis hymenoides* (Roem. & Schult.) Ricker, Indian ricegrass, M. M. Hoover of the Soil Conservation Service suggested the study of the germination requirements of this seed.

Huntamer (1)[3] has presented results on the different strains of *Oryzopsis hymenoides*, the nature of the resistance of the seed to germination, and of various treatments to overcome this resistance. She gives a rather complete review of the literature on the distribution of this plant and its value as a forage grass. Stoddart and Wilkinson (2) have published on the treatment of the seed with concentrated sulfuric acid.

METHODS

The seed was furnished by various Soil Conservation agencies through the courtesy of M. M. Hoover. The seed as received was cleaned by means of an air blast blower. The "seed" referred to in this paper is the fruit with the attached lemma and palea. The blown seed was placed in water for 5 minutes to make a more complete separation of the heavv and light seed. Stoddart and Wilkinson (2) concluded that only those seeds which sank in water within 5 minutes had a reasonable chance to grow.

The seed was germinated in duplicate tests of 100 seeds each on various media in Petri dishes. Paper toweling in the Petri dishes was a satisfactory substratum for the treated seeds which germinated quickly. After an extended period in the germinator, the toweling tended to lose its water-absorbing capacity. For this reason, a sandy soil or a mixture of peat and sand in Petri dishes was more satisfactory for non-treated seed that required a long period for germination.

The seed was considered as germinated when it had produced a normally developed root and plumule. The sprouts grew more slowly at the low temperatures, developing into a "stubby" but otherwise normal sprout. In many of the tests of the non-treated seed and of the seed pretreated with approximately 71% sulfuric acid for 30 minutes, the root lacked the vigor to push itself from within the lemma and palea and so grew coiled around the caryopsis. The two types of sprouts just described were counted as germinated. The most common abnormality, both in the treated and non-treated seed, was the lack of root development. Seeds showing this abnormality were not recorded as germinated.

The seed was germinated over a wide range of constant and alternating temperatures. The alternation of temperature was obtained by transferring the test from one chamber to another, the test remaining at the first temperature listed for 17 and at the second temperature for 7 hours daily. The temperature of the germi-

[1]Contribution from the Division of Fruit and Vegetable Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C. Received for publication October 28, 1939.

[2]Junior Botanist.

[3]Figures in parenthesis refer to "Literature Cited", p. 41.

nation chambers was controlled within 1 degree of that listed. In order to obtain light exposure accompanying a high temperature alternation, the test was placed in a north window of an air conditioned building for the 17-hour period. The room temperature varied from 16° to 24° C.

To prechill the seed, it was placed in Petri dishes on top of moistened peat and sand or soil and held at 3° C for various lengths of time. The temperature of the 3° chamber varied between 2° and 5°. The time of counting is computed from the day the seed was placed to prechill.

To treat the seed with sulfuric acid, the seed was placed in a small porcelain crucible, covered with an excess of acid, and stirred constantly for the designated time, then washed in running tap water for 30 to 45 minutes and dried thoroughly before placing to germinate. The approximately 71% sulfuric acid used was made by diluting 3 parts of concentrated sulfuric acid (sp. gr. 1.84) with 1 part distilled water by volume.

Germination figures summarized in Tables 1, 2, and 3 are in all cases mean values, based on duplicate tests of 100 seeds each. In Table 2, half percents have been raised to the next higher percentage. Values for error and tests of significance of difference have been calculated by the analysis of variance method as adapted by Snedecor (3).

PRESENTATION OF RESULTS

TEMPERATURE

In preliminary tests, the effect of constant temperatures of 3°, 10°, 15°, 20°, 25°, 30°, and 35° C, temperatures alternations of 10° to 25°, 15° to 25°, 10° to 30°, 20° to 30° (with light), 15° to 35°, 20° to 35°, 20° to 40°, 25° to 15°, 35° to 10°, room to 10°, room to 25°, and room to 35°, and of prechilling at 3° for various periods was determined on untreated blown seed of *O. hymenoides*. The constant temperature of 3° or prechilling at 3° for 28 days or longer before placing at a higher temperature proved to be the best for germination. Germination was very slow at this low temperature, requiring 100 or more days. The germination of the different samples varied from 2 to 62%. The other temperatures gave exceedingly low results. The above results are in accordance with the conclusions presented by Huntamer (1) regarding embryo dormancy.

STORAGE TEMPERATURE AND GERMINATION TEMPERATURE

The blown seed of three samples of 1937 seed was stored in sealed containers at three different controlled temperatures and in paper bags in an air-conditioned room on January 12, 1938. Sample No. 766900 was received from Kansas and sample No. 766908 from New Mexico as 1937 seed, sample No. 766906 was collected near Greenhorn, Colorado, in June 1937, and all three samples were received in the laboratory in December 1937. At the time the seed was put in storage the moisture content was approximately 7%.

On July 1, 1938, the seed was placed to germinate at the seven different temperatures shown in Table 1. The difference between sample No. 766908 and samples Nos. 766900 and 766906 is of high significance. Sample No. 766908 appeared to be of low viability, germinating very poorly at all temperatures regardless of storage conditions and with few sound seed remaining at the end of the test.

TABLE 1.—*Germination in 125 days of seed of Oryzopsis hymenoides previously held in storage at four different temperatures, means of duplicate 100 seed tests.**

Sample No.	Temperature of storage chamber, °C	Number of Observations	Percentage germination response at indicated temperatures: 3° C	15° C	20° C	15–25° C	20–30° C	20–35° C	20–40° C	Mean: Number of Observations	Mean: Germination, %
766900	Room	2	31.0	33.5	30.0	34.5	35.0	28.0	19.0	14	30.14
	30°	2	30.5	46.0	29.5	48.0	49.5	29.0	22.0	14	36.35
	20°	2	30.5	27.5	5.5	14.5	12.0	5.0	12.5	14	15.35
	2°	2	21.0	27.5	4.5	5.0	3.5	2.5	3.0	14	9.57
	Mean for sample	8	28.25	33.62	17.37	25.5	25.0	16.12	14.12	56	22.85
766906	Room	2	41.0	29.0	25.5	23.0	20.0	17.5	17.5	14	24.78
	30°	2	51.0	49.0	33.0	47.0	44.0	40.5	29.5	14	42.0
	20°	2	24.5	13.0	5.5	12.0	11.0	5.5	6.5	14	11.14
	2°	2	14.5	7.5	5.5	5.5	6.5	4.5	0.5	14	6.35
	Mean for sample	8	32.75	24.62	17.37	21.87	20.37	17.0	13.5	56	21.06
766908	Room	2	4.0	10.0	9.5	5.0	6.5	8.0	6.0	14	7.0
	30°	2	8.5	10.5	8.5	5.0	11.5	5.5	9.0	14	8.35
	20°	2	3.5	1.5	2.0	2.5	5.0	0.5	3.0	14	2.57
	2°	2	3.5	0.5	3.5	4.5	2.5	3.5	4.0	14	3.14
	Mean for sample	8	4.87	5.62	5.87	4.25	6.37	4.37	5.5	56	5.24
Mean for room.		6	25.33	24.16	21.66	20.83	20.5	17.83	14.16	42	20.64
Mean for 30°.		6	30.00	35.16	23.66	33.33	35.0	25.0	20.16	42	28.90
Mean for 20°.		6	19.50	14.00	4.33	9.66	9.33	3.66	7.33	42	9.68
Mean for 2°		6	13.0	11.8	4.5	5.0	4.16	3.5	2.5	42	6.35
Mean for all storage temperatures		24	21.95	21.28	13.53	17.20	17.24	12.49	11.04	168	16.39

*Minimum differences required for significance are: Between means of 2 observations, 15.61%; 6 observations, 4.68%; 8 observations, 3.88%; 14 observations, 2.82%; 24 observations, 2.10%; 42 observations, 1.58%; 56 observations, 1.35%.

The difference between 30° C and room storage is significant for sample No. 766900, and of high significance for sample No. 766906, showing 30° storage as superior. Seed stored at 30° germinated best and about the same at 3°, 15°, 15° to 25°, and 20° to 30°, but even at these temperatures there were many sound seeds remaining at the end of the test. The seed stored at 20° and at 2° was more dormant. The difference in the germination of the seed stored at these two temperatures and that stored at the higher temperatures is significant, and in most cases highly significant, especially at the higher germination temperatures.

Most of the germination at 3° C occurred between 63 and 125 days and between 10 and 35 days at the higher germination temperatures.

MECHANICAL SCARIFICATION

Scarification of the seed with emery paper or by rotating in a metal box with small gravel at a high speed for 5, 10, 15, 20, 30, and 40 minutes produced injury to the exserted embryo. Huntamer (1) found mechanical scarification with sand paper injurious to the embryo and endosperm. She obtained better results by removing the glumes from individual seeds with a needle.

TREATMENT WITH SULFURIC ACID

Preliminary treatments with concentrated sulfuric acid for 3, 5, 10, 15, and 20 minutes resulted in injury to the seed. Very low germination results were obtained.

A general survey of treated and non-treated seed.—The heavy seed of eight samples separated in water was treated with approximately 71% sulfuric acid for 0, 30, 45, 60, and 120 minutes and germinated at 20° to 30° C with light and 3°. The results are given in Table 2.

In all cases the optimum acid treatment for a particular sample gave higher results than the test on untreated seed. In general 45 to 60 minutes treatment with acid appeared to be the best. However, there was an indication that samples with large dark seed (samples Nos. 760104 and 769271) required a longer acid treatment. Even after the most favorable acid treatment some samples had apparently sound seed remaining at the end of the test. This was most pronounced with the two samples with large dark seed, which were of the type described by Huntamer (1) as being extremely difficult to germinate. Sample No. 757542 which germinated 90% after treatment was probably the type designated as small dark seed by the other writers. The heavy seed in this study, with the exception of the three samples mentioned above, were of medium size and of a black to brown color.

There does not appear to be any consistent difference between germination temperatures for treated seed; for some samples 20° to 30° C is better and for other samples 3° is better.

Heavy and light seed.—The blown seed of samples Nos. 766900, 766906, and 766908 was placed in water for 5 minutes to determine the percentage of heavy and light seed. The heavy and light seed were then treated separately with approximately 71% sulfuric acid for 0, 30, 45, 60, 90, and 120 minutes, respectively, and then germi-

nated at 20° to 30° C with light and at 3°. The results of the germination test on the heavy seed is given in Table 3 and the analysis of variance in Table 4.

TABLE 2.—*Germination of eight samples of seed of Oryzopsis hymenoides after various treatments with approximately 71% sulfuric acid.*

Sample No.	Place of collection	Date collected	Percentage germination in 84 days after treatment with approximately 71% H_2SO_4 for indicated minutes					
			0	30	45	60	90	120
			Germination Temperature 20° to 30° C					
757442	Arizona	July 14, '36	0	—	—	85*	—	—
760104	Arizona	————	6	16	28	43	47*	41
757542	Wyoming	————	34	—	90*	90†	43	—
751463	New Mexico	July 22, '36	2	—	—	66	77‡	—
769271	New Mexico	June 19, '38	1	0	1	3	36§	—
766908	New Mexico	1937	7	6	13	22*	7	1
766900	Kansas	1937	30	70	80	83‡	81	23
766906	Colorado	June 1937	31	73	79	69	29	1
			Germination Temperature 3° C					
757442	Arizona	July 14, '36	24	—	—	88*	—	—
760104	Arizona	————	6	18	16	25	38	27
757542	Wyoming	————	60	—	67	74	23	—
751463	New Mexico	July 22, '36	30	—	—	57	56	—
769271	New Mexico	June 19, '38	0	0	0	3	16	—
766908	New Mexico	1937	4	11	15	22*	10	0
766900	Kansas	1937	76	78	87	89*	90*	22
766906	Colorado	June 1937	53	75	78	81*	45	1

*Few sound seed remaining. †No sound seed remaining.
‡Several sound seed remaining. §Many sound seed remaining.

The differences among the samples for the heavy seed are of high significance. At the germination temperatures of 20° to 30° C with light, the 45- and 60-minute treatments are significantly better than 30 minutes and the differences when compared with the other treatments are highly significant. At the germination temperature of 3°, the 60-minute treatment is significantly better than the 30-minute treatment, with the 45-minute treatment falling midway between. The other treatments are significantly lower than the 30-minute treatment at this temperature. The mean of all samples at the two germination temperatures shows no difference between the 45- and 60-minute treatments and these two are far superior to the other treatments. The mean of all samples germinated at 3° is of high significance in comparison with the mean of all samples germinated at 20° to 30°, but this significance is due to the differences at the unfavorable treatments since the 30-, 45-, and 60-minute treatments do now show this significant difference. The 90- and 120-minute treatments, except the 90-minute treatment on sample No. 766900, produced injury causing fungus infection. As shown by Huntamer (1), the indurated lemma and palea prevented the germination of untreated samples. Although pre-treatment with acid hastens the germination

at 3°, it is still comparatively slow, germinating mostly between 21 and 49 days, while the germination of the treated seed at 20° to 30° is practically complete in 21 days.

TABLE 3.—*Germination in 84 days of heavy seed of Oryzopsis hymenoides at indicated temperatures and specified treatment, means of duplicate 100 seed tests.**

Sample No.	No. of observations	Percentage germination response after treatment with approximately 71% H_2SO_4 for indicated times						Mean	
		0 minutes	30 minutes	45 minutes	60 minutes	90 minutes	120 minutes	No. of observations	Germination %
			Germination Temperature 20° to 30° C with Light						
766900	2	30.0	70.0	79.5	82.5	80.5	22.5	12	60.83
766906	2	30.5	73.0	78.5	68.5	28.5	1.0	12	46.66
766908	2	7.0	5.5	12.5	22.0	7.0	0.5	12	9.08
Mean	6	22.5	49.5	56.83	57.66	38.66	4.0	36	38.86
			Germination Temperature 3° C						
766900	2	75.5	77.5	86.5	88.5	89.5	21.5	12	73.16
766906	2	52.5	75.0	77.5	81.0	44.5	0.5	12	55.16
766908	2	4.0	10.5	15.0	21.5	10.0	0.0	12	10.16
Mean	6	44.0	54.33	59.66	63.66	48.0	3.66	36	46.13
			Means						
	12	33.25	51.91	58.24	60.66	43.33	3.83	72	42.49

*Minimum differences required for significance are: Between means of 2 observations, 18.45%; 6 observations, 5.53%; 12 observations, 3 63%; 36 observations, 2 01%.

TABLE 4.—*Analysis of variance of germination data given in Table 3.*

Source of variation	Degree of freedom	Mean square
Total	71	——
Temperature	1	960.88
Treatments	5	4,719.31
Sample	2	21,022.26
Temperature × treatment	5	178.18
Temperature × sample	2	196.27
Treatment × sample	10	886.86
Treatment × temperature × sample	10	100.06
Remainder (error)	36	18.43

A separate analysis of the germination results with various treatments of the heavy and light seed shows that there was no significant difference in response of the heavy and light seed to the duration of acid treatments. The light seed was of low viability.

DISCUSSION

The seed of *Oryzopsis hymenoides* is resistant to germination. Huntamer (1) found two types of dormancy in the seed, *viz.*, mechanical

and embryo dormancy. The first could be remedied by removing the coat restriction and the second by moist, low temperature stratification or by long periods of dry storage. The present work gives some evidence of the two types of dormancy, but not a sharp distinction between them. Most samples germinated after the removal of the coat restriction by acid. Huntamer (1) showed that indurated lemma and palea and the grain coats were not impermeable to water. She found total exclusion of oxygen prevented germination. She demonstrated that pricking the swollen grain over the embryo had a stimulating effect on some grains, being more effective on non-dormant than dormant embryos.

In contrast to the results of other investigators, the present work showed concentrated sulfuric acid to be injurious. However, suitable treatment with approximately 71% sulfuric acid was found to be effective. Some samples did not give complete germination even then, indicating embryo dormancy. Although a complete age series was not available for observation, embryo dormancy appeared more related to seed type than to the age of the seed. The temperature at which the seed is stored affects the degree of dormancy. Seed with 7% moisture stored in sealed containers at 30° C was less dormant than similar seed stored at 20° or 2°. Huntamer (1) observed that seeds from plants grown under low moisture and high temperature conditions were more dormant than those from plants grown under moderate rainfall and temperature conditions.

Huntamer (1) distinguished types or races that responded differently to conditions of germination and to acid treatment. There is some evidence of similar differences in the seed used in this study. Large dark seed appeared not only to possess a more protracted embryo dormancy than the small or medium sized brown to black seed but to require a longer acid treatment. Huntamer states that concentrated sulfuric acid scarification of large dark "seeds" gave negative results. The highest results obtained by the writer on this type of seed was 35 and 45% after pre-treatment with acid. Huntamer found that small, light-colored seeds required 10 minutes and the small, dark seeds 15 minutes treatment with concentrated sulfuric acid when treated at 19° C. When treated at 25°, 12.5 to 17.5 minutes and 15 to 20 minutes, respectively ,were required for the two classes of seed. Treatment with 25 and 50% acid did not remove the mechanical restraint of the glumes. Stoddart and Wilkinson (2) found 15 to 45 minutes for very small seed and 60 to 120 minutes for very large seed to be the optimum treatment with concentrated sulfuric acid. These acid treatments were apparently made at room temperature. The writer found 45 to 60 minutes treatment with approximately 71% sulfuric acid at room temperature to be the optimum treatment for small or medium sized brown to black seed with a possible indication of 90 minutes as better for large dark seed.

There appeared to be no difference in the length of treatment required for the heavy and light weight seed as separated by placing in water for 5 minutes. The low results with the light seed agree with those of Stoddart and Wilkinson (2) who found it to be of little value, detracting from the value of the bulk of seed.

For untreated seed the germination temperature of 3° C or 15° is best. However, the germination was very slow and not complete at these temperatures. For acid-treated seed 3° or 20° to 30° is equally good, but the germination is quicker at the higher temperature. Huntamer (1) gives 20° as the optimum germination temperature.

Tests were made on the effect of using a dilute solution of potassium nitrate to moisten the substratum. The results with potassium nitrate agree with those of Huntamer (1) who found the seed to be non-sensitive.

Although at some of the germination temperatures, the seed was exposed to daylight, no definite check was made in complete darkness; however, Huntamer (1) stated that there was no benefit of the exposure of the seed to light.

SUMMARY

1. A study was made of various treatments to overcome the resistance to germination of seed of *Oryzopsis hymenoides*.

2. A medium of sandy soil or of a mixture of sandy soil with peat was good for extended tests because it provided a uniform moisture supply over the entire period. Moistened paper toweling appeared to be as good for treated seed which germinated more promptly.

3. Fresh untreated seed germinated best at 3°, or by prechilling at 3° for at least 28 days before placing at a higher temperature.

4. Seed stored at high temperatures (room and 30°) was less dormant than seed stored at lower temperatures (20° or 2°).

5. Untreated seed held in storage at high temperatures germinated at higher temperatures than that held in storage at low temperatures. However, a low germination temperature of 3° or 15° appeared to be the optimum regardless of previous storage.

6. Fresh untreated seed required over a hundred days for germination at a low temperature.

7. Maximum germination of untreated seed held in storage occurred between 63 and 125 days when germinated at 3°; between 10 and 35 days when germinated at higher temperatures.

8. The seed of *O. hymenoides* was not sensitive to potassium nitrate.

9. Mechanical scarification produced injury to the exserted embryo.

10. Treatment of the seed with concentrated sulfuric acid resulted in injury.

11. The mechanical resistance of the indurated lemma and palea could be overcome by treatment with approximately 71% sulfuric acid for 45 or 60 minutes. Large dark seeds probably required longer treatment.

12. Some samples of seed of *O. hymenoides* appeared to have a dormant embryo since the seeds did not germinate after the mechanical resistance of the lemma and palea had been removed.

13. Seed receiving the optimum acid treatment germinated equally well at 3° or 20° to 30°.

14. After the optimum acid treatment, the germination of apparently viable seed of most samples was complete in 21 days at 20° to 30°, and in 70 days at 3°.

15. By placing heavy "blow" seed in water for 5 minutes, the lighter seed floated off. This seed was of doubtful value.

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THE EFFECT OF THE VETCH CROPPING HISTORY AND CHEMICAL PROPERTIES OF THE SOIL ON THE LONGEVITY OF VETCH NODULE BACTERIA, *RHIZOBIUM LEGUMINOSARUM*[1]

W. B. ANDREWS[2]

THE longevity of soybean nodule bacteria (*Rhizobium joponicum*) in relation to the length of time since soybeans had been grown was studied by Wilson (3).[3] He found that "there seemed to be no relationship between the frequency of the occurrence of the plant symbiont on the soil and the number of Rhizobium joponicum in the soil. There is no evidence that the reaction or the moisture content of the samples, or the influence of the crop on the soil when the samples were collected, exerted a dominating influence on the number of Rhizobium joponicum that were found in the soil samples."

Hawkins (2) found that the growth of vetch for one year on sandy soil did not supply sufficient nodule bacteria for vetch on the following year.

In 1897 Duggar (1) found that dipping vetch seed into muddy water made from soil which had grown wild vetch for several years increased the yield from 232 to 2,540 pounds of cured vetch hay per acre. He tested four soils which had not previously grown cultivated vetch or related crops. The increase in yield due to inoculation was 38, 38, 186, and 466% of the yield without inoculation for the four soils.

The purpose of the work reported in this paper was to determine the need of vetch for additional inoculation after growing vetch for one or more years on a soil and to determine the relation of chemical properties of the soil to the longevity of the nodule bacteria (*Rhizobium leguminosarum*), and the relation of one chemical property to another.

PROCEDURE

Composite samples of soil were obtained from fields with known vetch history. The surface inch of soil was removed before taking the soil to be used. A quart fruit jar full of soil was obtained from each field. A top without the rubber was put on the jar, which permitted the exchange of gases without a serious change in moisture content.

The presence of the vetch nodule bacteria was determined by inoculating vetch seed for 30 feet of row with a fruit jar top full of soil which is approximately 60 grams. The yield data are averages of four to six replications.

Available phosphorus was determined by the Truog method; soluble iron was determined by the Comber method combined with a photolometer for taking the reading; and pH was determined by the use of a glass electrode. The data are reported in Table 1.

[1]Contribution from the Agronomy Department, Mississippi Agricultural Experiment Station, State College, Miss. Approved by the Director as Paper No. 21, new series. Received for publication November 8, 1939.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 47.

TABLE I.—*Longevity of vetch nodule bacteria.*

Soil No.	Vetch history*	pH	Yield in lbs. per acre green weight†	Available phosphorus, p.p.m.	Soluble iron, p.p.m.
101	0–3$_1$	4.2	3,117	12	41
103	0–5$_1$	4.2	2,556	28	89
102	0–5$_1$	4.3	2,013	40	36
119	0–3?	4.4	2,517	14	3
104	0–6$_1$	4.6	2,488	75	8
19	0–2$_2$	4.7	4,201	126	15
122	0–2$_2$	4.7	2,517	16	2
126	0–?	4.7	2,314	17	4
134	0–1$_1$	4.7	2,822	40	7
11	No.–V.	4.8	1,491	102	11
108	0–3$_1$	4.8	5,169	20	5
120	0–4$_1$	4.8	3,838	31	5
106	0–8$_1$	4.8	4,951	43	8
117	0–3$_1$	4.8	4,492	14	4
136	0–2$_3$	4.8	2,101	203	92
54	0–3$_1$	4.8	4,598	16	13
110	0–2$_1$	4.8	3,799	15	3
113	0–2?	4.8	2,023	24	6
51	0–5$_1$	4.9	1,249	29	23
118	0–3$_3$	4.9	3,485	15	4
29	?–1	4.9	1,767	28	29
116	1–1$_2$	4.9	2,556	13	5
25	0–1?	5.0	3,461	32	6
133	0–1$_3$	5.0	1,186	18	5
112	No.–V.	5.0	3,862	12	3
114	1–2$_1$	5.0	1,767	12	9
52	0–3$_1$	5.0	3,746	30	14
131	0–3$_1$	5.1	3,499	99	5
36	3–4$_1$	5.1	3,291	25	21
37	3–4$_1$	5.1	2,967	33	13
28	1–1$_3$	5.1	5,121	32	23
18	0–1$_1$	5.1	4,162	143	9
26	0–1?	5.2	4,274	43	4
115	1–1$_3$	5.2	3,165	19	2
49	No.–V.	5.2	1,815	144	20
109	0–2$_1$	5.2	4,143	12	2
107	0–2$_1$	5.3	3,606	9	2
105	0–6$_1$	5.3	5,025	106	7
21	0–1$_1$	5.3	2,856	130	13
203	0–5$_3$	5.3	2,004	9	2
31	0–1?	5.3	6,776	26	5
38	3–S?	5.3	1,588	44	28
20	0–2?	5.4	4,274	27	6
7	No.–V.	5.4	1,467	129	12
12	9–1?	5.4	3,025	140	15
34	3–S?	5.4	2,120	47	14
27	1–1?	5.4	5,653	45	5
48	0–1$_3$	5.4	5,682	51	13
127	0–3$_1$	5.5	2,294	5	1
22	0–2$_1$	5.5	4,937	30	15
23	0–1$_1$	5.5	5,750	124	15
125	0–S$_2$	5.5	3,194	14	2
135	0–1$_1$	5.5	3,640	28	2

*Vetch history: First figure indicates number of years since vetch; second figure, years of vetch; S = several but the exact number is unknown. 1, 2, 3, 4 farmers' opinion of success of vetch. 1 good; 2 fair; 3 poor; 4 failure; ? unknown.

TABLE 1.—*Concluded.*

Soil No.	Vetch history*	pH *	Yield in lbs. per acre green weight	Available phosphorus, p.p.m	Soluble iron p.p.m.
128	2–1$_1$	5.5	3,882	24	5
33	3–S?	5.5	4,714	48	15
202	0–1$_1$	5.6	4,240	19	3
35	3–3?	5.6	2,042	43	12
111	0–1$_1$	5.6	3,901	9	3
30	0–3$_1$	5.6	6,156	36	30
132	0–1$_1$	5.6	3,494	11	2
9	0–8$_1$	5.6	5,692	200	7
43	No.–V.	5.6	1,955	90	9
53	No.–V.	5.6	4,821	35	10
1	No.–V.	5.7	3,378	195	11
6	1–6$_1$	5.7	4,671	34	6
121	0–1$_2$	5.7	3,596	23	2
130	0–S$_1$	5.7	3,010	10	2
13	3–10$_1$	5.8	5,460	193	11
2	No.–V.	5.8	3,741	170	9
10	No.–V.	5.8	4,104	161	7
4	0–2$_1$	5.8	5,881	102	6
46	0–1?	5.8	5,895	51	16
50	No.–V.	5.9	944	36	1
40	No.–V.	5.9	1,515	27	11
15	5–S?	6.0	6,791	6	3
24	0–1?	6.0	5,687	34	7
45	2–1?	6.0	5,624	152	6
47	0–1?	6.0	6,379	19	12
17	5–S$_1$	6.0	5,363	213	0
14	5–S$_2$	6.0	6,074	186	3
201	0–2$_2$	6.1	2,914	13	2
32	4–S?	6.2	3,853	21	7
41	No.–V.	6.3	1,888	112	3
8	No.–V.	6.4	2,168	197	0
5	No.–V.	6.4	4,613	143	3
16	5–S$_1$	7.1	5,261	60	2
42	No.–V.	7.1	3,451	248	2
124	Wild V.$_1$	7.2	6,011	29	1
44	1–1$_1$	7.8	4,724	133	3
Commercial inoculation..........			4,598		
No inoculation..................			1,176		

RESULTS AND DISCUSSION

RELATION OF SOIL REACTION TO AVAILABLE PHOSPHORUS

Various workers have shown that soil treatments in the field which reduce the acidity of the soil increase the available phosphorus. In the data reported, the soils were taken at random over the counties involved without reference to previous fertilizer treatment. The data show that there is a tendency for the soils which approach a neutral reaction to have a higher available phosphorus content than extremely acid soils, but that the tendency is only slight. There were many extremely acid soils with a high to very high available phosphorus content. Also certain of the soils with a high reaction were low in phosphorus.

RELATION OF SOLUBLE IRON TO SOIL REACTION

At a pH of 6.0 and above the soluble iron varied from a trace to 12 p.p.m. The number of soils in this range was only 15. Soils 101, 102, and 103 are soils very high in organic matter and they were also very high in soluble iron. The soluble iron in the soils with a pH of 4.4 to 5.9 varied from 2 to 92 p.p.m. and there was no indication that the soluble iron was associated with the reaction over this range.

There was no relation between soluble iron and available phosphorus.

LONGEVITY OF VETCH NODULE BACTERIA

(*Rhizobium leguminosarum*)

The soils obtained were used to inoculate vetch seed. One fruit jar top full of soil was used to inoculate seed for 30 feet of row. The seed were planted on soil which had not previously grown vetch.

The yield of vetch without inoculation was 1,176 pounds of green vetch per acre. The yield of vetch inoculated with commercial inoculation was 4,598 pounds of green vetch per acre.

There were 15 soils which had not previously grown vetch or related cultivated plants. When three of these soils were used to inoculate vetch, the yields were over 4,000 pounds of green vetch per acre. When five of them were used, the yields were between 3,000 and 4,000 pounds of green vetch per acre. Four soils produced yields which were close to the yields of the check. The other three soils produced increases in yield over the check which indicate the presence of the nodule bacteria. From these data it appears that eight of the soils had sufficient bacteria for vetch even though no vetch or related cultivated plants had been grown previously and that three more of them may have had enough bacteria for vetch planted on the field from which the soil came.

Thirty-four out of the 77 soils which had previously grown vetch produced over 4,000 pounds of vetch, 12 of them produced over 1,000 pounds more vetch than the commercial inoculation. Apparently 12 soils had nodule bacteria which were superior to the commercial culture and 34 had nodule bacteria in one fruit jar top full of soil per 30 feet of row which were just as good. Nineteen of the soil produced 3,000 to 4,000 pounds of vetch per acre, and only two soils produced no measurable increase in yield, while only three soils made low increases in yield. Seventy-two out of the 77 soils used to inoculate vetch increased the yield over 800 pounds, 53 increased it over 1,800 pounds, 34 increased it over 2,800 pounds. The commercial culture increased the yield 3,422 pounds.

OBSERVATIONS ON DIFFERENT TREATMENTS

Soils Nos. 9 and 10 are directly comparable. Soil No. 9 has been in a vetch-cotton rotation for 8 years; soil No. 10 has been in cotton without vetch for a number of years and probably no vetch was ever grown on this soil. When used for inoculation, vetch soil No. 9 produced 5,692 pounds of vetch and No. 10 produced 4,104 pounds.

Soil No. 14 came from a spot in the field where cotton died early due to wilt; soil No. 15 came from nearby where the cotton did well. Both soils increased the yields of vetch as if they had an excellent supply of nodule bacteria.

Where basic slag was applied to Austrian winter peas, the yield of vetch when the soil was used for inoculation was increased from 2,556 to 3,165 pounds per acre (soils Nos. 115 and 116).

Soil No. 136 had a very low value for inoculating vetch. It had had one year of good vetch. The good vetch was produced by planting the seed in contact with basic slag which was necessary for the vetch growth.

There was no difference in the value of soils Nos. 131 and 132 when used for inoculation. One of them had one year of vetch; the other had 3 years of vetch.

Soils Nos. 201 and 202 came from the same field, and the main difference between them is that soil No. 201 is a sandy soil and No. 202 is a sandy loam. Soil No. 201 produced 2,914 pounds and soil No. 202 produced 4,240 pounds of green vetch per acre when used to inoculate the vetch.

RELATION OF LONGEVITY OF VETCH NODULE BACTERIA TO CHEMICAL PROPERTIES OF SOIL

The vetch nodule bacteria were apparently not as abundant in soils below a pH of 5.0 as in soils above a pH of 5.0, but many extremely acid soils had an ample supply of nodule bacteria and some soils with a pH above 5.0 had a relatively low quantity of nodule bacteria.

There was no relation between the available phosphorus and soluble iron and the longevity of nodule bacteria.

RELATION OF NUMBER OF YEARS OF VETCH ON SOIL AND LONGEVITY OF VETCH NODULE BACTERIA

There is apparently no relation between the number of years of vetch or the number of years since vetch and the value of the soil for inoculating vetch.

SUMMARY

Ninety-two samples of soil were obtained from fields or woods which had different vetch histories. Fifteen of the soils had never been planted to vetch and no related cultivated plants had been grown. Seventy-seven soils had grown vetch for one or more years, and it had been from none to several years since vetch had been grown. The soil was used to inoculate vetch at the rate of one fruit jar top full (about 60 grams) of soil per 30 feet of row. The soil inoculation was compared to commercial and no inoculation. The data show that:

1. Twenty per cent of soils which had not previously grown vetch and 50% of the soils which had grown vetch, with the quantity of soil used, were probably equal to or superior to commercial culture for inoculating vetch.
2. Twelve of the soils produced over 1,000 pounds more vetch than commercial culture.

3. Vetch nodule bacteria were present in 96% of the soils which had previously grown vetch.

The data suggest that:

1. Sixty-nine per cent of the soils would not need inoculation when vetch is planted on them.
2. Ninety-six per cent of the soils which had grown vetch probably would not need inoculation.
3. Four per cent of the soils which had grown vetch previously would need inoculation.
4. Nodule bacteria apparently do not thrive as well in sandy soils as in heavier soils.

CONCLUSION

Soils which produce a good crop of vetch without the addition of lime in the drill do not need inoculation when vetch is planted on the field again. Soil inoculation where excellent vetch has been grown is equal to or superior to commercial culture.

A heavy suspension of clay from soil which has previously grown good vetch is a satisfactory method of inoculating vetch.

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RETENTION BY SOILS OF THE NITROGEN OF UREA AND SOME RELATED PHENOMENA[1]

JOHN P. CONRAD AND C. N. ADAMS[2]

INTEREST in the application of fertilizers dissolved in the irrigation water has been growing in the western states. Principles governing the behavior of the different nutrient units in the various inorganic fertilizers have for the most part been realized for years. Knowledge of these principles is becoming more widespread among those employing this easy method of fertilizer distribution. The retention of ammonium ions by the soil against leaching and the remaining of nitrates in the soil solution in a leachable form have recently been demonstrated by plant response (3).[3] These studies were inaugurated to extend our knowledge with regard to the organic fertilizer, urea.

Evidence in the literature indicates some small adsorption of urea by colloids, including soil colloids. Van Harreveld-Lake (12) recovered on the average 88% of urea in a 1:2 soil-water extract after 48 hours. In comparative trials 0.5 to 3% of the nitrogen of NH_4Cl and 96 to 100% of the nitrogen of $NaNO_3$ was recovered. He attributed the retention of the urea to adsorption by certain soil constituents, probably humus. Przylecki, *et al.* (10) secured 2 to 5% adsoprtion of urea on animal charcoal from urea solutions of varying concentrations. In comparable tests Grettie (6) secured adsorption of 1.9% of the original urea present on silica, 2.94% on alumina, 0.3% on iron oxide, and 5% on fuller's earth. Kniaseff (9), using Grettie's technic again, secured 5% adsorption on fuller's earth from an aqueous solution of urea, but in alcoholic solution only 0.95%. These observations from other fields of science are of special interest as nearly all of these substances or substances closely resembling them occur in many soils.

In comparative leachability trials with various soluble nitrogenous fertilizers, Benson and Barnette (1) mixed urea with Norfolk sand. After incubation for 1 day, 35.1% of the nitrogen applied as urea was leached out, 35.0% being recovered as urea; after 4 days, 16.4% with 16% recovered as urea; after 10 days, 3.8% with none of it recovered as urea; and after 21 days, 18.7% with all of it recovered as ammonia and nitrate nitrogen. The effect of incubation in transforming urea to ammonium carbonate and in turn into HNO_3, and a few, at least, of the resultant effects on the soil have been worked out in some detail (2, 8).

Two mechanisms seem available to cause the retention of the nitrogen of urea by the soil, *viz.*, a small amount of adsorption by the soil of the urea itself and the transformation of urea to ammonium carbonate followed by the strong retention of the latter.

PRELIMINARY EXPERIMENTS

Preliminary tests to determine experimentally the behavior of urea and $CaCN_2$ were conducted by using the method developed by Crafts (4). A solution of each of these two compounds was allowed

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication November 10, 1939.

[2]Associate Professor and Graduate Student respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 54.

to drip down upon a continuous column of dry soil deficient in nitrogen, in a demountable tube. After the column had been completely wet by the solution, it was sectioned in 6-inch depths, each section placed in a separate pot, and cropped to milo. Table 1 gives the yields of plants secured. The yields decreased with depth with both of these compounds, indicating a reaction between the soil and some of the nitrogen of these compounds as they percolated through it. Citations above indicate a possibly small adsorption of urea, and inferentially the cyanamide ion, by the soil itself. Retention of the rest of the nitrogen held back from solution could be caused by a continuing but rapid transformation to $(NH_4)_2CO_3$ and the strong retention of the latter at or close to the point of change. The larger yields from sections near the bottom are attributed to nitrates leached down.

TABLE 1.—*Nitrogen retention from percolating solutions by continuous columns of Yolo loam as shown by subsequent plant response.*

Percolating solution	Transverse section, depth in feet from top of column							
	0–0.5	0.5–1.0	1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	3.0–3.5	3.5–4.0
Urea	8.3*	9.2	7.8	5.4	3.9	3.6	4.2	6.0
Calcium cyanamide	8.0	6.2	4.9	3.4	2.0	2.4	3.6	4.6

*Yields of green milo in grams per pot. Three check pots not fertilized and not subject to percolation averaged 3.1 grams per pot

To try out microbial transformations as a cause of retention, subsequent percolations at four different temperatures were conducted. One was kept as close to freezing as possible to reduce microbial activity to the minimum, i.e., at 2° C in the cold storage rooms of the Pomology Division; another was kept high enough to be above the thermal limit of activity for urea bacteria, i.e., at about 90° C in a large electrically heated drier; and two were kept at convenient intermediate temperatures about 11° and 40° C. Columns of five pots each were employed using essentially the same procedure as previously described (3). The yields are reported in Table 2. In two soils, Yolo loam and Fresno fine sandy loam, there was evidence which strongly suggested retention of nitrogen at 2° C. The evidence with all three soils showed retention of nitrogen at all other temperatures except 90° C. The percolation at 90° C with Yolo loam suggested very little retention of the nitrogen of urea at that temperature.

Most microbial activity is slowed down to a minimum below 5° C, but Rubentschik (11) has experimented with two organisms that grow and decompose urea below 0° C. If organisms of this type were present and were immediately very active in our percolations, a point that may very seriously be questioned, the results secured might be adequately explained. If such were the case, however, other explanations would not be excluded.

As an alternative these preliminary data, therefore, suggest (a) that there may have been but little adsorption of urea as such by the solid phase of the soil, assuming no change in the adsorption capacity

of the soil by heating to 90° C; (b) that probably during percolation at the lower temperatures, 2° to 40° C, urea gradually but somewhat rapidly hydrolyzed to $(NH_4)_2CO_3$, the latter being strongly retained where it was formed; (c) that the factor causing hydrolysis was practically as effective at 2° C as at the other temperatures and might, therefore, be catalytic rather than microbial; and (d) that the catalyst causing hydrolysis of urea which is inactivated by heating to 90° C could be a hydrolytic enzyme adsorbed on the soil colloids.

TABLE 2.—*Retention by soils of the nitrogen from urea solutions percolated at different temperatures as shown by subsequent plant response.*

Temperature during percolation, °C	Yield of green milo, grams per pot					
	1st pot in column	2nd pot in column	3rd pot in column	4th pot in column	5th pot in column	Check*
			Yolo Loam			
2°	8.4	8.5	4.5	4.1	3.6	2.6
11°	13.4	6.0	3.3	3.4	3.6	
40°	14.2	9.1	5.0	3.7	3.3	
90°	4.5	4.6	5.9	5.8	4.9	
			Imperial Silty Clay Loam			
2°	3.7	3.9	3.4	3.4	2.4	2.2
11°	3.7	5.4	2.8	2.9	1.5†	
40°	12.0	2.6	1.9	2.7	0.0†	
			Fresno Fine Sandy Loam			
2°	10.2	7.0	4.8	6.2	1.8	3.2
11°	5.7	8.0	7.6	6.7	5.2	
40°	8.0	8.1	7.7	7.7	4.6	

*Value for unfertilized and unpercolated pots of same soil.
†Values for second planting; first did not germinate

REPLICATED PERCOLATION STUDIES

To test the possibility of catalysis, percolations were conducted with various soil treatments. In addition to the checks these were as follows:

1. *Percolation under toluene.*—This antiseptic should inhibit, if not entirely inactivate soil micro-organisms leaving largely catalytic activity remaining. Consequently, columns of pots were set up as described by Conrad and Adams (3) in a garbage can with 10 mls. of toluene added to the dry soil of each pot, and 10 mls. mixed with each solution before percolation. Except as operations momentarily required, the garbage can was kept covered. A strong odor of toluene was evident each time the lid was removed.

2. *Percolation with preheated soil.*—The results of the percolation at 90° C suggested a heat inactivation of the catalytic agent or enzyme. If this was so, preheating of the soil prior to carrying on percolation and then subsequent percolation at normal temperatures should be equally effective. In preheating, a lot of the normal soil was moistened with distilled water in a crock and placed for 48 hours

in a chamber maintained between 80° and 90° C. After this time, the soil was spread out and dried at this same temperature. This soil was stored dry as a stock lot and was handled in the same manner as the untreated dry soil. Actually this soil was slightly drier as stored than the normal soil and, therefore, in weighing out the respective lots, a little more actual oven-dry soil was obtained. In percolating these pots with the various solutions, the preheated soil, therefore, gave less volume of percolate than the others.

Again, if the transformations in the soil are catalytic, a slower rate of percolation should give a greater difference in the resulting growth between the pots in a column; therefore, two rates of percolation were tried as follows:

1. *Rapid.*—The solution was added as rapidly as it would penetrate the soil. In each case, all of the solution had disappeared from the surface of the top pot in 7 hours or less.

2. *Slow.*—In this case, each solution was added to its respective column in five nearly equal portions, applied approximately 12 hours apart. The columns under toluene received solutions over a period of 49 hours; the other columns, over a period of 44½ hours. In an additional two or three hours, most of the excess solution undoubtedly drained down; however, the columns were allowed to stand for an-

TABLE 3.—*Retention by Yolo fine sandy loam of the nitrogen from solutions of urea percolated at two rates and through soil variously treated, as shown by the yields of the subsequent green growth of milo.*

Soil treatments	Yield of green milo, grams per pot							
	Rapid percolation, about 7 hrs.				Slow percolation, about 50 hrs.			
	1st pot in column	2d pot in column	3d pot in column	Column number	1st pot in column	2d pot in column	3d pot in column	Column number
				Urea				
None	13.8[1]	11.3	9.9[4]	4	15.9[3]	13.4[2]	6.0	3
Percolation under toluene	15.2[3]	12.7[2]	9.7[4]	4	13.2	13.1[1]	6.2	3
Preheating to about 85°C	14.9	15.0[1]	12.2[5]	3	15.1	14.6[2]	11.8[5]	5
				Distilled water[6]				
None	2.1	1.8	1.8	5	—	—	—	—
Percolation under toluene	2.3	2.5	2.2	4	—	—	—	—
Preheating to about 90°C	3.0	3.5	3.6	5	—	—	—	—

Statistically different (5, p. 112) from the value to the right and from the pot next below it in the column.

[1]P = 0.01 or less

[2]P lies between 0.01 and 0.02

[3]P lies between 0.02 and 0.05

Statistically different, P = 0.01 or less, (5, p. 114)

[4]From the values for the 3rd pots of the corresponding columns percolated slowly.

[5]From the two values immediately above.

[6]All values for the urea treatments, P less than 0.01, (5, p. 114) greater than corresponding values for distilled water.

other 24 to 36 hours before being dismantled. Each column was percolated with 500 mls. of total solution. The urea solutions contained 20 m.at.N[4] per liter or 10 m.at.N per column.

As toluene might be injurious to crop growth, the pots were allowed to aerate for about a week. They were then all cropped to milo and otherwise handled as reported previously (3). The yields secured are given in Table 3, and the cultures are illustrated in Fig. 1.

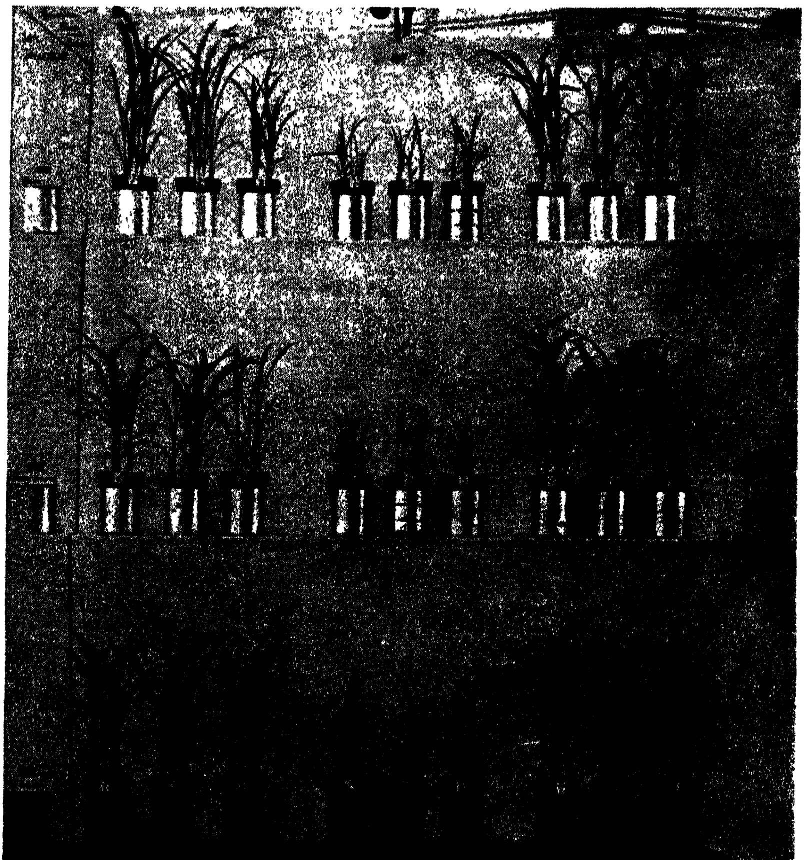

FIG. 1.—Effect of soil treatments and rates of percolation on the retention of the nitrogen of urea by Yolo fine sandy loam. Each group of 3 pots, marked 1, 2, and 3 were staked in a column and subjected to a percolating solution. All groups on the left were percolated slowly with urea; all groups on the right, rapidly with urea; and all groups in the center, with distilled water. The soil used for the cultures shown in the top tier was untreated; in the center tier, soil under toluene; and in the bottom tier, preheated soil.

At the time the percolation columns were dismantled, the percolates were measured and later analyzed for the concentration of urea

[4]Milligram atoms of nitrogen.

in each, Marshall's urease method as described by Hawk and Bergeim (7, p. 712) being used. Table 4 reports these data.

TABLE 4.—*Average volumes and concentrations of urea in percolates from columns for data in Table 3.*

Soil treatment	Rate of percolation			
	Rapid		Slow	
	Volume, mls.	Concentration of urea, m.at.N per liter*	Volume, mls.	Concentration of urea, m.at.N per liter*
None	97	1.35	70	0.07
Percolation under toluene..	78	0.43	69	0.03
Preheated to about 85°C .	44	1.54	13	0.48

*The urea solutions added to the top of the columns contained 20 m at.N (milligram atom of nitrogen) per liter.

The data of Table 3 disclose no significant differences between the results secured with and without toluene. Both normal soil and soil under toluene showed significant retention of nitrogen in the upper parts of the column. In every case, the bottom pots gave significantly lower yields than one or more pots above them. This was especially significant where the urea was percolated through slowly. Likewise, with the preheated soil, the bottom pots yielded significantly less than the middle pots of the column. The bottom pots of the normal soil and those percolated under toluene yielded significantly less than the bottom pots of the preheated soil. The rates of percolation with preheated soil apparently had very little effect upon the retention of the nitrogen of urea. The rate of percolation, however, with normal soil and that under toluene had a marked effect on the distribution of nitrogen. The yields of the bottom pots where percolation had been rapid were significantly higher than the yields of the bottom pots where percolation had been slow.

These data constitute good evidence that the transformations of urea in the soil, at least in so far as that which takes place during the relatively short time of percolation, was largely catalytic rather than microbial. Further evidence supporting this view is being gathered in a laboratory study, a report on which will be given later.

SUMMARY

1. In preliminary studies in which urea solutions were percolated through columns of dry soil and then the columns subsequently sectioned, the response of milo was used to indicate the final distribution of the nitrogen applied in the urea. Untreated soils progressively removed at least some of the nitrogen of urea and of $CaCN_2$ from solutions as they percolated through them. This property of the untreated soils was largely lost by percolating urea at 90° C, but persisted at 2°, 11°, and 40° C.

2. Though a small amount of adsorption and unusually great microbial activities might account for these data, an alternate explanation is a catalytic hydrolysis (independent of micro-organisms) of urea to ammonium carbonate during percolation with the subsequent strong retention of the latter.

3. To test the possibility of catalysis in the hydrolysis of urea, percolations were conducted with various soil treatments. No significant differences in the growth responses between the untreated soils and those percolated under toluene were disclosed. Significantly smaller amounts penetrated to the lowest pots of the columns with these two treatments than with soil preheated in a moistened condition to about 85° C and subsequently dried before percolation. A slower rate of percolation significantly decreased the amount of nitrogen reaching the lowest pots with the untreated and toluened soils, but not with the preheated soil.

4. The growth results as well as the analyses of the small amount of percolates from the columns are in agreement with the hypothesis that adsorption and a thermolabile catalysis were perhaps largely responsible for the retention of the nitrogen of urea by the untreated soil.

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THE SEGREGATION OF GENES AFFECTING YIELD OF GRAIN IN MAIZE[1]

MERLE T. JENKINS[2]

PRESENT-DAY maize breeding in the United States involves isolating self-fertilized lines, testing them, primarily for yield, in hybrid combination, and then utilizing the superior ones in F_1 hybrids of one kind or another. The value of the different inbred lines in the breeding program depends upon their general contributions to their hybrid progeny and particularly to the value of specific individual hybrids involving them. Experience has demonstrated these two characteristics to be correlated and that inbred lines imparting a high average yield to their hybrid progeny may be expected also to produce high yielding individual hybrids. Accordingly, it has become practice to test new inbred lines in top crosses, i.e., crosses with an open-pollinated, heterozygous variety, using the top-cross data as a measure of their ability to impart high average yield to their hybrid progeny, or, more conveniently, their yield prepotency.

Yield prepotency depends, of course, upon the number of dominant alleles favorable to yield carried by the different inbred lines and upon their relative importance. The rate at which fixation for yield prepotency occurs in an inbreeding program likewise is dependent upon these two factors. In an experiment reported by the writer in 1935 (2),[3] it was found that inbred lines of corn showed their individuality as parents of top crosses very early in the inbreeding process and remained relatively stable thereafter. This rather surprising situation was explained on the basis that yield was controlled by a large number of dominant genes, many of which have approximately equal effects. Essentially equal numbers of dominant alleles will be preserved by chance through the successive generations of selfing even though accompanied by segregation for particular dominant alleles. These data are all that are available in maize (or in any other organism so far as is known to the writer) on segregation for yield prepotency. They do not permit a precise determination of the amount of segregation for various reasons.

From the standpoint of practical corn breeding, it is important to know the earliest possible generation in which newly developed lines may be tested for yield performance. Early elimination of unpromising lines permits a concentration of effort on more promising material and should result in greater progress in the breeding operations.

It was decided, therefore, to obtain data on which a more precise estimate of the segregation for yield prepotency might be based. Two assortments of the genes influencing yield will affect the segregation for yield prepotency. When a maize plant heterozygous for many pairs of yield genes is self pollinated, the complement of genes re-

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[3]Figures in parenthesis refer to "Literature Cited", p. 63.

ceived by the different plants comprising its inbred progeny will vary in the number and in the particular dominant alleles present. When these progeny plants are used individually as the parents of top crosses, both the number of dominant alleles they contribute and the importance of the particular dominant alleles contributed will affect the performance of the resulting top cross. These two effects cannot be measured separately, but their combined value may be measured by the segregation for yield prepotency which they produce.

The first generation of inbreeding was chosen as the best one in which to obtain data on segregation for yield prepotency as it is greatest in this generation of inbreeding. The heterozygosis present in the original parents of the inbred lines will decrease in accordance with the series ½, ¼, ⅛, etc., with successive generations of selfing. With data available on the first generation of inbreeding, therefore, segregation in later generations may be computed readily. Using this information as a basis, it should then be possible to arrive at a reliable estimate as to the number of generations of selfing required to reduce segregation to a point at which the amount remaining offers little practical opportunity of extracting sub-lines that differ materially from the mean for the line in yield prepotency.

THE EXPERIMENT

Seven lines of Krug which had been selfed for one generation were selected as the parent lines in which segregation was to be determined. These lines came from among a group of 37 Krug lines first inbred at Ames, Iowa, in 1926. The lines were top crossed with the parent variety in 1929 after they had been inbred for three generations and the top crosses were compared for yield in 1930. Thirteen of the more promising lines were saved, new top-crossed seed was produced after succeeding generations of inbreeding, and the top crosses compared for yield and other characters. Three of the 13 lines were discarded after tests running through 1932. Top crosses of the remaining 10 lines were tested for a fourth time in 1933. The data on the acre yields of the top crosses of these 10 lines are shown in Table 1. The seven lines chosen for the present experiment are indicated in this table.

TABLE 1.—*Acre yields of top crosses between inbred lines of Krug and the parent variety.*

Inbred line	Acre yields in the season indicated				
	1930	1931	1932	1933	Mean
K675	40.0	71.9	77.2	73.6	65.7
K679*	39.7	75.8	71.3	80.9	66.9
K680	42.3	67.0	67.7	77.4	63.6
K682*	37.3	74.6	81.8	92.3	71.5
K683*	51.9	81.1	77.6	84.3	73.7
K685*	22.4†	70.4	74.7	79.2	61.7
K686*	37.9	79.8	79.5	86.3	70.9
K687*	31.1†	79.5	66.1	73.6	62.6
K689*	36.2	76.4	71.7	82.0	66.6
K690	49.9	81.8	87.4	88.0	76.8
Krug	37.5	76.5	75.1	79.9	67.3

*Inbred lines included in the present experiment.
†Sister progeny of the one tested in the later generations.

Average yields of the top crosses of the lines chosen ranged from 5.6 bushels below to 6.4 bushels above the yield of the parent variety. As far as the relative heterozygosity of the open-pollinated plants is concerned, they represented an entirely unselected population as nothing was known about them in this regard.

Remnant S_1 seed of the seven chosen lines was planted at Arlington Experiment Farm, Arlington, Virginia, in 1936 in ear rows 25 plants in length. Pollen was collected individually from at least 16 plants from each ear row, the pollen from each plant being applied to the silks of 25 plants of the Krug variety. No conscious selection was practiced either among the plants within the ear rows or among plants of the Krug variety. There may have been some natural selection, however, in favor of the surviving plants in the ear rows which failed to have 25 plants reach pollen shedding. Seed representing each top cross was prepared by mixing equal numbers of seeds from not less than 20 of the 25 ears pollinated with pollen from that plant.

The top crosses of the 112 individual inbred plants on Krug were compared for yield in 1937 on a very uniform piece of land near Columbus, Ohio, provided through the courtesy of the Dairy Husbandry Department of Ohio State University. Six seeds were dropped per hill and the plots later were thinned to three plants per hill. Ten replications of plots 2 by 10 hills were grown of each entry in the yield test. The test was laid out in 10 blocks, one block for each replication. Within each block the entries were arranged in seven groups of 16. Each group of 16 entries comprised the top crosses of the 16 sibling plants of one inbred line. The entries were distributed at random within the groups of 16 and the seven groups were distributed at random (with restrictions to equalize the distribution of the groups among seven columns of groups) within the blocks. Acre yields were computed on a basis of shelled grain with 15.5% moisture.

EXPERIMENTAL RESULTS

The acre yields of the 112 top crosses included in the test are shown in Table 2. In order to illustrate the segregation for yield prepotency in hybrids, the data are shown graphically in Fig. 1. In this figure the yield of the top cross of each plant is expressed as a deviation from the mean of the top crosses of the group of 16 sibling plants of the same line. The general mean acre yield for all groups was 62.7 bushels.

The analysis of variance of the acre yields is shown in Table 3. The variances among lines and among sibling plants within lines both are highly significant. We are most concerned here with the variance among siblings within lines, that is, with the average variance among the top crosses of the 16 sibling plants within each of the seven lines, each selfed for one generation. This variance of 77.21 is comprised of two portions, the error term (19.97) and the variance among sibling plants within lines (57.24). On the basis of theory the variance among the siblings within lines will successively be reduced in accordance with the series ½, ¼, ⅛, etc., in successive generations of selfing, while the error term will remain unchanged. Accordingly, the appropriate mean squares for the first eight generations of inbreeding were computed and are shown in Table 4.

The data in Table 4 indicate that under conditions similar to those of this experiment it should be possible to demonstrate significant segregation for genes affecting yield prepotency in hybrids in the

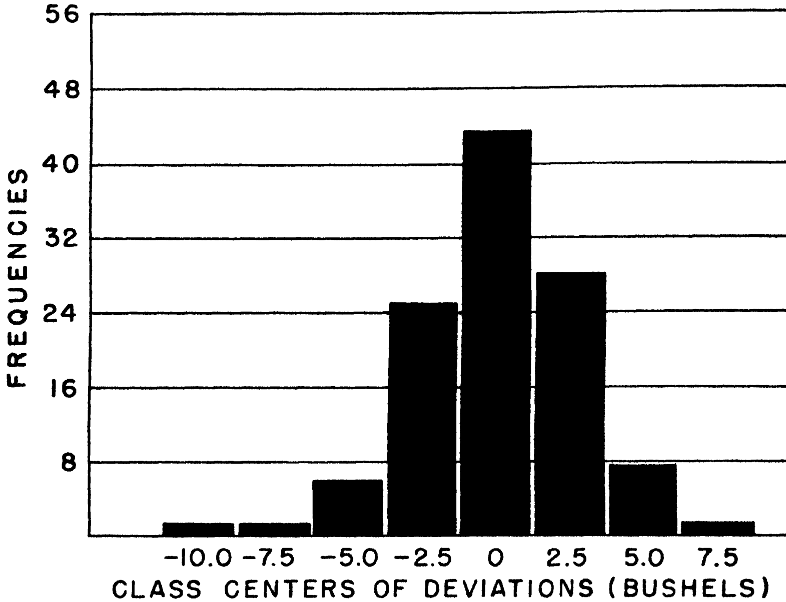

FIG. 1.—Frequency histogram of the deviations in acre yield of the top crosses of 112 S_1 plants from the means for their respective lines.

TABLE 2.—*Acre yields of grain in bushels for 112 Krug top crosses grown near Columbus, Ohio, 1937.*

Plant No.*	Acre yields in bushels of top crosses with plants of the inbred line indicated						
	K679	K682	K683	K685	K686	K687	K689
1	65.4	66.1	60.0	61.8	59.1	58.3	64.4
2	67.5	65.5	64.6	61.9	66.6	63.1	65.3
3	66.3	64.8	62.1	62.0	62.3	63.9	63.9
4	65.9	68.6	64.2	60.2	62.0	60.7	61.8
5	64.6	65.7	60.7	56.0	59.1	65.3	62.7
6	68.2	65.1	64.7	52.2	63.3	61.5	63.8
7	64.4	63.6	60.8	57.0	61.0	66.6	64.7
8	62.7	64.7	60.9	58.3	55.8	59.8	61.7
9	63.1	62.7	63.2	59.8	65.2	61.6	62.8
10	68.6	63.7	67.4	62.7	59.5	64.1	59.8
11	62.8	63.8	61.8	59.5	63.7	64.9	64.0
12	54.6	61.0	59.4	58.3	61.9	69.4	62.7
13	66.0	64.6	61.6	54.8	58.7	65.7	57.5
14	65.7	61.7	64.9	57.9	55.8	60.0	63.9
15	64.5	67.2	66.7	59.1	62.7	67.1	63.5
16	62.5	63.7	64.0	56.9	68.4	66.0	64.5
Group means	64.6	64.5	62.9	58.7	61.6	63.6	62.9

*Consecutive plant numbers of the plants from which pollen was collected; not necessarily the actual plant numbers within the rows.

seventh generation of selfing. The parental plants in the S_6 generation had on an average only 1.56% of the genes that were segregating in the original plant still in the heterozygous condition.

TABLE 3.—*Analysis of variance of the acre yields of top crosses of individual plants in one-generation Krug selfs, Columbus, Ohio, 1937.*

Source of variation	D/F	Sums of squares	Mean squares	F
Lines	6	4,081.93	680.32	34.07*
Sibling plants within lines	105	8,107.39	77.21	3.87*
Replications within lines	63	25,417.51	403.45	20.20*
Error	945	18,871.33	19.97	——
Total	1,119	56,478.16		

*Highly significant

TABLE 4.—*Variance and standard deviations among the acre yields of top crosses of sibling plants in successive generations of selfing, computed from the variance determined for the first generation.*

Generation	Hetero-zygosity* %	Mean square	F	Standard deviation (bu.)
Original plants	100.00	——	——	——
S_1	50.00	77.21	3.87†	2.8
S_2	25.00	48.59	2.43†	2.2
S_3	12.50	34.28	1.72†	1.8
S_4	6.25	27.13	1.36†	1.6
S_5	3.13	23.55	1.18†	1.5
S_6	1.56	21 76	1.09†	1.5
S_7	0.78	20.86	1.04†	1.4
S_8	0.39	20.42	1.02	1.4
Error		19.97		

*Average heterozygosity of the plants within the generation indicated which in turn is reflected in the variability among the plants of the generation following. The heterozygosity actually present in the original plants is taken as 100%.
†Highly significant.

From the standpoint of practical plant breeding, however, the segregation must be large enough to offer reasonable chances for the accomplishment of improvement by selection. A statistical demonstration that segregation exists is of no value in itself. Table 4 shows the standard deviation for yield in the first generation of inbreeding to be 2.8 bushels per acre. Within the first generation of inbreeding, therefore, the top crosses of two-thirds of the segregates should fall within 2.8 bushels of the mean for the line and there should be only 1 chance in 40 of obtaining a segregate whose top cross exceeds the mean of the line by as much as twice the standard deviation, or 5.6 bushels. This is only 8.9% of 62.7 bushels, the mean yield of all top crosses in the experiment. In a great majority of the general run of yield tests with corn having the usual five or six replications, differences as small as this are not significant statistically.

A reasonably low standard deviation in the first generation was anticipated on the basis of the earlier data (2); however, a standard

deviation as low as the one actually computed from these data was not expected. These results indicate that the segregation for yield prepotency among the plants within the first generation of inbreeding was so limited that the opportunity of selection for this character within lines even in this generation would not have been very promising. The envisioned computation of a later generation possessing the desired amount of stability, therefore, is superfluous.

Had these results been anticipated, the experiment would have been designed to permit a direct comparison of the segregation for yield prepotency occurring among plants of the parent open-pollinated variety as contrasted with that among sibling plants within lines selfed for one generation. Such a comparison would permit a computation of the relative emphasis that efforts on selection in the two classes of material should most profitably receive.

In the absence of a critical experiment especially designed to permit a comparison of this kind, the writer cast about for data on the segregation for yield prepotency occurring among plants of a variety which might be compared with these on segregation within one-generation selfs. No suitable data are available in the literature. The ear-to-row tests of previous years should have provided information on this subject, as they were in reality yield tests of the top crosses of individual plants with the variety, the individual plants serving as female parents. These early tests, however, were not designed in such a manner as to permit of statistical analysis.

A few data are available from another experiment also conducted by the writer in 1937 but for an entirely different purpose. This experiment comprised an ear-to-row yield test of open-pollinated ears of corn harvested from two-eared plants of the Krug variety. The test was grown on Arlington Experiment Farm. There were six replications of single-row plots 14 hills in length with three plants per hill. The experiment contained 36 entries, 35 ear rows, and one entry of the Krug variety. The analysis of variance for acre yields is shown in Table 5.

TABLE 5.—*Analysis of variance of acre yields of top crosses on 2-eared Krug plants, Arlington Experiment Farm, 1937.*

Source of variation	D/F	Sums of squares	Mean square	F
Blocks	35	3,267.824	93.366	1.59*
Ear rows	35	11,142.046	318.344	5.43†
Error	145	8,504.586	56.652	
Total	215	22,914.456		

*Significant.
†Highly significant.

The variance among ear rows in Table 5 can not be compared directly with that in Table 3 as the level of productivity in the two experiments differed rather widely. The pertinent data from the two experiments are assembled in Table 6. They indicate much greater segregation among the plants of the variety than among the siblings within one-generation selfs, but they do not permit a precise comparison.

TABLE 6.—*Comparison of the variability in the yield of top crosses of plants of the Krug variety and plants in first-generation Krug selfs.*

Material	Mean squares	No. of plots	Vari-ance	Stand-ard de-viation (bu.)	Mean yield (bu.)	Coeffi-cient of varia-bility
Open-pollinated plants within the Krug variety	318.344	6	53.057	7.3	91.1	8.0
Sibling plants within the first generation of selfing	77.21	10	7.721	2.8	62.7	4.5

These data further emphasize the greater chances of obtaining lines of outstanding performance in hybrids through selection *among* large numbers of inbred lines rather than *within* lines. They also add to the accumulating evidence indicating that the yield prepotency of lines in hybrids, as measured by their top crosses, may be determined very early in the inbreeding period.

SYNTHETIC VARIETIES FROM SHORT-TIME INBRED LINES

On the basis of the 1935 data previously mentioned (2), which indicated that inbred lines became stable for yield prepotency early in the inbreeding period, the writer has informally suggested the possibility of producing synthetic varieties among short-time inbred lines for use in sections where hybrid corn may not be economically feasible. As the data presented here indicate even less segregation within lines than those obtained earlier, they seem to emphasize the possibilities of the method and a description of it may be worth while at this time.

Hybrid corn has become definitely established in the Corn Belt and doubtless will be used extensively there until a more efficient breeding method is developed. There are many sections around the margins of the major corn-producing areas, however, where growing conditions are severe and the development and maintenance of inbred lines and the production of hybrid seed corn is a more hazardous and expensive undertaking. It is questionable whether the use of hybrid corn will become an established practice in some of these sections.

The early individuality and stability of inbred lines for yield prepotency would seem to permit of their use in a breeding procedure that should insure more productive varieties than can be obtained by any of the modifications of mass selection now in use. The procedure contemplated involves the production of synthetic varieties among short-time inbred lines. The essential steps in the procedure are:

1. The isolation of one-generation selfed lines.
2. Testing of these lines in top crosses for yield and other characters to determine their relative endowments with respect to genes affecting these characters.
3. Intercrossing of the better-endowed selfed lines to produce a synthetic variety.

4. Repetition of the above process at intervals after each "synthetic variety" has had a generation or two of mixing, possibly with the inclusion of lines from unrelated sources.

There are many ways in which the above procedure may be carried out. For example, the one-generation lines may be produced, planted in a field of the parent variety, and detasseled in order to obtain top-crossed seed. Or the initial plants may be double-pollinated for the production of selfed and crossed seed on the same ear as suggested by Sprague (4). If the parent variety happens to be a prolific variety, one of the ears on the plants may be selfed and another used for crossing, or the additional ear or ears may be allowed to open-pollinate. The latter actually is the procedure that was followed in the case of the experiment with the two-eared Krug plants previously described.

The method has some superficial similarity to the older ear-to-row method of breeding. It differs fundamentally from the ear-to-row method, however, in that the germ plasm of the tested plants is maintained by selfing the plants and this selfed seed of the superior individuals is mixed and increased in developing the new strain. In the ear-to-row method of breeding, the male parentage of the selected plants was not controlled and as a result represented the variety average.

It is envisioned that the procedure outlined should be a more or less continuous one, with improved varieties or strains released to growers as they are obtained. A sufficient number of lines should be included in each synthetic strain to permit growers to select seed from it by mass selection during the interval of 3 to 4 years required to complete the next cycle of isolating lines, testing them in hybrids, and recombining the selected lines into a new synthetic strain to replace the old one. Experience will have to determine the minimum number of lines necessary for this purpose. It would seem, however, that there should not be less than about 10.

Jenkin (1) coined the term "strain building" to describe the methods he employed in breeding perennial rye grass which resemble in some particulars the procedure outlined above. The term was used by him and later by Kirk (3) in a very broad sense to include any system of mating by which a strain is built up by crossing from carefully selected plants. The parental plants usually were selected on the basis of a progeny test, but no particular distinction was made between the use of inbred or crossbred progeny for testing purposes. Ample experience in corn indicates that the performance of inbred lines as such is not highly correlated with their performance in hybrids, and the use of a broad term which gives no implication of the kind of testing procedure could not be recommended for this crop.

There are hardly sufficient data available on synthetic varieties in corn to form much of a basis for estimating the possibilities of improvement through the use of such synthetics among short-time lines. On the basis of theory, however, the use of such synthetics should definitely offer promise of greater improvement than can be accomplished by simple mass selection. The method, however, is not suggested for areas where hybrid corn is economically feasible.

SUMMARY

1. The segregation of genes affecting yield of grain in maize, as reflected in the differences among the individual plants to impart high average yield to their hybrid progeny, was determined in the first selfed generation of seven plants of the Krug variety. The ability of the plants to impart high average yield to their hybrid progeny, or, more conveniently, their yield prepotency, was measured by testing the top crosses between the individual plants and the parent variety.

2. The average standard deviation among the top crosses of individual plants within the seven S_1 populations was 2.8 bushels per acre, indicating only 1 chance in 40 of obtaining a plant within this generation whose top cross would yield 5.6 bushels or 8.9% above the mean for the line.

3. The limited segregation for yield prepotency permits, and emphasizes the importance of, early testing of the lines to determine their relative endowment with respect to factors affecting yield.

4. A method of breeding involving the production of synthetic varieties among short-time inbred lines is suggested for areas where hybrid corn may not be economically feasible.

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THE RELATIONS OF COLOR TO GERMINATION AND OTHER CHARACTERS OF RED, ALSIKE, AND WHITE CLOVER SEEDS[1]

D. C. SMITH[2]

WHILE assisting with crops judging work at Oregon State College the writer's attention was attracted to the question of relative values of the various seed colors in red, alsike and white clovers. It had been assumed that darker shades of purple were preferable in red clover seed and similarly that the darker shades of black or green in alsike clover were most desired. Bright yellow color was thought to be most sought for in white clover. Since few data seemed available in the literature the bases for these assumptions were uncertain.

In 1912, Gernert (3)[3] wrote that, "There is a popular demand for purple-colored clover seed, the general impression being that purple color indicates maturity, viability and vigor. It is quite well established that purple in clover seed has no relation to yield, either of seed or hay."

Eastman (2) in the same year, observed that, "Farmers, and consequently seedsmen, prefer seed of a dark color because they believe it looks more mature and appears richer in food material."

Recently responses to a letter of inquiry sent to four large northern seed companies of the Middle West and East, dealing extensively in clover seed, indicated agreement to exist as to the general preference for darker colored lots in red and alsike clovers, while in white clover yellow-colored seed was thought to be preferable. These choices were admittedly based to a large extent on attractiveness to the eye of the prospective buyer.

Inquiry was also made of several agronomists in middle western clover seed producing states. Purple-colored seeds in red clover were thought to be more desirable from the trade viewpoint, though it appeared questionable if any fundamental cultural basis for this existed. The possible relation of purple color to maturity, plumpness, and hard seed percentage was suggested. One agronomist expressed belief in existence of a preference for medium dark seed in alsike clover, and others presented the view that dark seeds would be preferred. It appeared to be a general belief that yellow color in white clover was preferable to brown or reddish shades.

The brief experiments discussed here were completed before inquiries were made of seedsmen and agronomists. Though originally planned and finished as a test using few samples and small quantities of seed from one locality, it is thought that the results obtained may be of interest.

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[3]Figures in parenthesis refer to "Literature Cited", p. 71.

REVIEW OF LITERATURE

Many studies have been made upon the relations of viability, hard-seededness, and longevity of clover seed. Reference to these have been omitted except as they relate specifically to color comparisons. The relations of seed size to later growth in clovers and other plants have been subjects for numerous experiments not reviewed here.

Miller and Pammel (4), in experiments with red and white clovers, as well as with other seeds, observed higher germination to occur in large seeds. Eastman (2) compared weights of purple and yellow seeds in 14 samples of red clover. In every sample purple seeds averaged more in weight than yellow. Von Rumker, cited by Eastman (2), found yellow seeds to be heavier than others in red clover. Dymond (1) reported that in only one sample of 85 did yellow seeds of red clover exceed purple in weight. Intermediate colors averaged about the same in weight as purple.

Williams (5) reported the results of extensive experiments in the analysis of color and other characters in red clover seed samples. The literature, reviewed by the same writer, indicated considerable disagreement to exist in results of studies on the relation of color to weight. Most workers observed yellow seeds to be inferior in weight, while some reported no relation to exist. Williams' results agreed with the latter in this respect though large variations were noted among varieties. Purple seeds were found to be generally heavier than yellow seeds from the same plants. No relation was observed between rate of germination and seed weight in red clover.

Germination of purple and yellow seeds in 14 lots of red clover by Eastman (2) showed a higher average percentage of germination and a lower proportion of hard seeds for the purple color. Statistical examination of the data indicates that the average differences were not significant. Preyer, cited by Eastman (2), observed light-colored seeds to germinate much better than the darker seeds. Dymond (1) noted no significant differences among purple, intermediate, and yellow seed colors in red clover as to germination and hard seeds when tested 8 months after harvest.

EXPERIMENTAL METHODS

Five lots each of red, alsike and white clovers were used in these studies. The samples were obtained from seed laboratory lots reduced in size using a Boerner sampler. All of the samples were grown in Oregon the previous season, being about 7 months from harvest when the tests were made. The white clover was of the Ladino variety. They were commercial lots harvested, threshed, and cleaned by ordinary farm machinery. The quality of the samples, judging by purity and appearance, was somewhat better than average for such seeds. The aliquots studied ranged from 3.4 to 5 grams, 1.3 to 3.0 grams, and 2.1 to 3.3 grams in red, white and alsike clovers, respectively.

Four color separations were made in each clover species. All normal seeds in each lot were grouped in one or another of these classes. Brown or shrunken seeds were discarded in red and alsike and shrunken seeds were eliminated in white clover. The limits of each color group were established arbitrarily with the effort being made to keep the ranges similar in each of the several samples separated.

Red clover was divided into purple, yellowish-purple, purplish-yellow, and yellow classes. The intermediate groups were those predominantly one color but not entirely so. Similarly, alsike clover seed was classified as black, greenish-black,

blackish-green, and green. The white clover color separations were red, yellowish-red, reddish-yellow, and yellow.

Germination tests were made on blotters and in soil in a standard germinator at a room temperature fluctuating near 20° C. The seeds on moistened blotters were allowed to germinate 5 days and notes were taken on the third and fifth days. The soil germination tests were made in small paper boxes, seeds being covered approximately ¼ inch deep in a sterilized sandy soil. Observations were recorded 5, 7, and 12 days following seeding.

Duplicate germination tests of 100 seeds were made on blotters and each color class in each seed lot was studied separately. Seeds from the same color classes of the several lots were bulked for the soil germination test and seeded in quadruplicate. Germination on blotters was recorded on the basis of total and weak sprouts. "Hard" seeds were also noted. The latter were considered to be those remaining ungerminated and without signs of decomposition at the end of the period, whatever the reason.

The data for the germination tests on blotters were practically indentical at the third and fifth days. Consequently, only the percentages for five days have been considered. The percentages of germination at 12 days have been included for the tests in soil. Though 5- and 7-day observations were obtained, no distinct differences were observed. Similarly, data on weak seedlings have been omitted since color differences were, for the most part, insignificant.

The analysis of variance was used in the reduction and summary of the data. Twice the standard error of a difference has been taken as the least significant value. Tabular details of the analysis have been omitted to allow brevity.

RESULTS

RED CLOVER

Summary data for red clover are listed in Table 1. Considering weight of seeds, the least significant mean difference was 0.005 gram. Purple seeds were significantly heavier than purplish yellow and yellow seeds and yellowish purple exceeded yellow in this respect.

The least significant difference among colors in total blotter germination was 11.0%. In this respect yellow, purplish-yellow, yellowish-purple, and purple ranked in the order given, all other colors being significantly higher than purple. The value of F indicated a significant difference to exist among lots.

Significant differences existed among the several colors in proportions of hard seeds, with a least significant difference of 15.9%. The percentages of hard seeds in the purple class were significantly higher than those for lighter colors. The interaction of colors and lots was also significant.

The values for soil germination in Table 1 are comparable only for the averages of the color groups since the lot identity, as previously indicated, was not maintained in these tests. In the soil tests error exceeded other components of variation, no significant differences being indicated among colors.

In order of percentage occurrence in the samples the colors ranked yellowish-purple, purplish-yellow, yellow, and purple.

TABLE 1.—*Summary data of color separations and germination percentages in red clover seed samples.*

Lot No.	Weight in grams per 100 seeds	Blotter germination, %		Soil germination, %*
		Total	Hard seeds	
		Purple		
1	0.148	54†	46†	81
2	0.148	40	60	75
3	0.148	91	9	66
4	0.169	40	60	61
5	0.181	40	60	—
Ave.	0.159	53	47	71
		Yellowish Purple		
1	0.148	60	40	75
2	0.147	76	24	68
3	0.148	93	7	80
4	0.170	73	27	68
5	0.174	80	20	—
Ave.	0.157	76	24	73
		Purplish Yellow		
1	0.144	67	33	65
2	0.141	71	29	66
3	0.140	92	8	82
4	0.171	80	20	72
5	0.167	81	19	—
Ave	0.153	78	22	71
		Yellow		
1	0.141	68	32	61
2	0.137	71	29	71
3	0.131	96	4	79
4	0.171	81	19	76
5	0.167	79	21	—
Ave.	0.149	79	21	72

*Each mean an average of four tests on composite color lot.
†Each value an average of duplicate tests.

ALSIKE CLOVER

In Table 2 summary data for alsike clover seed are given. Black, greenish-black, blackish-green, and green rank as listed in order of decreasing seed weights. The least significant difference was 0.0012 gram. The three darker-colored groups differ significantly from each other.

The least significant difference in blotter germination was 23.47%. Black and greenish-black were similar and significantly higher than green in total germination. Blackish-green was considerably higher than green. An interaction between colors and lots was indicated by the F value obtained.

TABLE 2.—*Summary data of color separations and germination percentages in alsike clover seed samples.*

Lot No.	Weight in grams per 100 seeds	Blotter germination, %		Soil germination, %*
		Total	Hard seeds	
		Black		
1	0.066	64†	36†	78
2	0.076	89	11	79
3	0.070	69	31	66
4	0.071	93	7	70
5	0.070	90	10	—
Ave.	0.071	81	19	73
		Greenish Black		
1	0.063	61	39	73
2	0.073	90	10	67
3	0.068	78	22	75
4	0.069	94	6	81
5	0.067	92	8	—
Ave.	0.068	83	17	74
		Blackish Green		
1	0.058	62	38	64
2	0.072	37	63	62
3	0.065	35	65	58
4	0.064	91	9	62
5	0.066	86	14	—
Ave.	0.065	62	38	62
		Green		
1	0.058	32	68	71
2	0.068	50	50	65
3	0.064	39	61	71
4	0.063	60	40	64
5	0.065	36	64	—
Ave.	0.064	43	57	68

*Each mean an average of four tests on composite color lot.
†Each value an average of duplicate tests.

Variations in percentages of hard seeds in the color lots were significant. The least significant difference was 26.22% with green notably different and significantly exceeding other colors.

The value of F for colors in germination in soil exceeded the .05 point, the least significant difference being 6.84%. Accordingly, only the blackish-green group was significantly different, being lower among the color classes.

In percentages of the different colors greenish-black, black, blackish green, and green occurred in decreasing frequency.

WHITE CLOVER

Summary data for white clover are given in Table 3. The colors rank as red, reddish-yellow, yellowish-red, and yellow in average weight with a least significant difference of 0.0013 gram.

TABLE 3.—*Summary data of color separations and germination percentages in white clover seed samples.*

Lot No.	Weight in grams per 100 seeds	Blotter germination, %		Soil germination, %*
		Total	Hard seeds	
Red				
1	0.049	33†	47†	51
2	0.069	76	24	51
3	0.048	52	48	41
4	0.056	50	50	51
5	0.055	57	43	—
Ave	0.056	58	42	61
Yellowish Red				
1	0.047	61	39	63
2	0.069	83	17	65
3	0.047	51	49	62
4	0.055	54	46	66
5	0.054	57	43	—
Ave	0.054	61	39	65
Reddish Yellow				
1	0.051	67	33	57
2	0.069	97	3	63
3	0.046	56	44	59
4	0.055	64	36	61
5	0.053	55	45	—
Ave	0.055	68	32	59
Yellow				
1	0.041	74	26	73
2	0.067	97	3	78
3	0.045	69	31	75
4	0.053	73	27	70
5	0.052	65	35	—
Ave	0.052	76	24	74

*Each mean an average based on four tests of composite color lot.
†Each value an average of duplicate tests.

Colors were significantly different in blotter germination, rating in the order of yellow, reddish-yellow, yellowish-red, and red. The least significant difference was 7.52%. Lots differed significantly.

Red, yellowish-red, reddish-yellow, and yellow ranked in order in percentage of hard seeds, with a least significant difference of 6.76%.

Under soil germination conditions colors differed significantly in total seeds sprouted, with a least significant difference of 4.81%. Dif-

ferences between yellow and other colors and between yellowish-red and reddish-yellow were therefore significant.

In percentage by weight of the various colors reddish-yellow, yellowish-red, yellow, and red occurred in decreasing frequency.

DISCUSSION

A general summary of the results previously presented is given in Table 4. In this table preferences as listed are based upon significant differences only. High seed weight and germination and low percentages of hard seeds have been assumed to be desirable. In the present studies only seedling vigor in germination has been recorded. The relation of seed color to the later development of the plant is to a considerable extent problematical.

TABLE 4.—*Summary indicating color preferences in clovers for the several respects studied.*

Character	Preference		
	Red	Alsike	White
Weight in grams per 100 seeds	Purple or yellowish purple	Black	Red
Blotter germination, total	Yellow, purplish yellow, or yellowish purple	Greenish-black, black, or blackish green	Yellow
Hard seeds	Yellow, purplish yellow, yellowish purple	Greenish-black, black, or blackish green	Yellow or reddish yellow
Soil germination	No preference	Greenish-black, black, or green	Yellow

Williams (5) has pointed out that seed color in red clover may be influenced by genetic factors and environment. Stapledon, cited by Williams, noted differences to exist in proportions of the various colors in red clover seed lots from different strains and several countries. Reports as to what extent similar conditions exist in white and alsike clovers have not been seen. In recognition of these facts study of numerous samples from many sections would be desirable before inclusive generalizations are made.

SUMMARY

1. Five lots each of red, alsike, and white clover seed were separated individually into four color classes and data obtained on average seed weight, percentage in the sample, germination on blotters and in soil, and hard seeds.

2. Purple and yellowish purple seeds averaged higher in weight than other colors in red clover. Darker-colored seeds were also heavier in alsike and white clovers.

3. Intermediate seed colors were generally most numerous in all clovers studied. Dark colors were frequent in alsike and less so in red and white clovers.

4. In total germination of red clover on blotters, yellow or yellowish seeds were superior. Total germination favored darker colors in alsike clover and yellow in white clover.

5. Hard seeds were most frequent in purple and purplish groups in red clover, in green and blackish-green in alsike clover, and in red and yellowish-red in white clover.

6. Germination in soil was highest in the darker colors in alsike clover and yellow was superior in white clover. Color differences in soil germination of red clover were very slight.

7. Average number of seeds per pound calculated for the samples studied were red clover, 293,600; alsike clover, 677,000; and white clover, 836,100.

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REGISTRATION OF IMPROVED WHEAT VARIETIES, XIII[1]

J. Allen Clark[2]

TWELVE previous reports present the registration of 58 improved varieties of wheat. In 1938, three varieties were registered.[3] Four varieties have been approved for registration in 1939, as follows:

Varietal name	Reg. No.
Wabash	324
Renown	325
Coronation	326
Regent	327

WABASH, REG. NO. 324

Wabash (C. I. 11384)[4] was developed by selection in cooperative experiments of the Department of Botany, Purdue University Agricultural Experiment Station, Lafayette, Ind., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The original head selection, C. I. 5308, was made from Fultz at Columbia, Mo., in 1913. This original head proved to be a natural hybrid, as it segregated for a number of characters, including glume color and disease resistance. Wabash is the result of a series of selections of which the final selection was made at the Purdue University Agricultural Experiment Station in 1924. It is superior to standard soft red winter wheats in yield, winter hardiness, and resistance to leaf rust and mosaic. Wabash is tall, with white mid-strong straw, awnleted spikes, white glabrous glumes, and soft red kernels. It has been under test for 8 years at Lafayette, Ind., and, in the fall of 1938, was approved for commercial distribution both by the Purdue University Agricultural Experiment Station and the Illinois Agricultural Experiment Station. The Purdue University Agricultural Experiment Station applied for its registration.

Yields and other data upon which registration was based are shown in Table 1.[5]

RENOWN, REG. NO. 325

Renown (C. A. N. 1856; R. L. 716; C. I. 11635) was developed from a cross between H-44 and Reward made in 1926 at the Dominion Rust Research Laboratory, Manitoba Agricultural College, Winni-

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 7, 1939.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, member of the 1939 Committee on Varietal Standardization and Registration charged with the registration of wheat varieties.

[3]Clark, J. Allen. Registration of improved wheat varieties, XII. Jour. Amer. Soc. Agron., 30:1037–1042. 1938.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

[5]For further information on Wabash wheat, see Report of Progress, 1915–1934, Soils and Crops Experiment Farm, Purdue University Agricultural Experiment Station. 1935.

peg, Manitoba. Selection R. L. 716 was made in 1927 and this strain was tested for yield and quality at an increasing number of stations in Canada from 1929 to 1937, when it was first distributed for commercial growing. The variety was reselected in 1932 and a single line strain (R. L. 716.6, C. I. 11947) was increased and distributed in 1939, in which year it was made one of the "uniform varieties" grown in plat experiments at all cooperating spring wheat stations in the United States. Renown was developed by the Cereal Division, Dominion Experimental Farms System, and this Division applied for its registration.

TABLE 1.—*Comparative yields and leaf rust resistance of Wabash and other standard winter wheats at Lafayette, Ind., 1930–38.*

Variety	Yield in bushels per acre									Leaf rust average†
	1930	1931	1932	1933	1934	1935	1937*	1938	Average	
Wabash (new)	30.1	45.3	28.6	32.6	37.4	40.6	23.6	30.5	33.6	5.9
"Michigan Amber"‡	29.1	41.9	28.5	30.8	38.6	30.1	19.6	29.2	31.0	73.8
Purkof	31.4	46.0.	26.5	24.9	40.1	32.2	8.1	27.4	29.6	31.3
Fultz	28.0	28.4	28.5	28.6	26.7	28.6	18.7	22.8	[illegible]	—

*Soil infested with wheat mosaic.
†Average 1931 to 1938
‡Synonym of Red May.

The superior characters reported for Renown are high yield, medium early maturity, and resistance to stem rust, leaf rust, and bunt. It has awnleted spikes, white glabrous glumes, short dark red kernels, and red coleoptiles.

Table 2 presents the yields reported upon which registration was based. The application, however, was accompanied by large annual mimeographed reports giving the individual station yields, milling and baking data, etc.

TABLE 2.—*Comparative yields of Renown and standard hard red spring wheats grown in nursery (six replications) experiments at various stations in western Canada.*

Variety	1934	1935	1936	1937	1938	Average	Percentage of Marquis
Number of stations	11	13	12	14	15		
Renown (new)	28.8	29.3	17.2	23.2	28.6	25.4	121.0
Ceres (standard)	31.6	21.2	18.8	21.5	22.5	23.1	110.0
Marquis (standard)	28.5	19.4	17.4	19.9	19.8	21.0	100.0

CORONATION, REG. NO. 326

Coronation (C. A. N. 1915; R. L. 729; C. I. 11475) was developed from a cross between Pentad (red durum) and Marquis made in 1925 at the Dominion Rust Research Laboratory, Winnipeg, Canada. The

selection resulting in Coronation was made in 1927 and the wheat was tested for 9 years or until 1937, when it was distributed. The superior characters reported for Coronation are high yield and resistance to stem rust, leaf rust, and bunt. Unlike the other two new Canadian wheats, Renown and Regent, which obtained their rust resistance from H-44, a sister strain to Hope, the Coronation resistance came originally from Pentad durum and is the result of a species hybrid. Coronation is awned and has white glabrous glumes and dark red kernels. Milling and baking data place Coronation in a different quality category from that in which Renown and Regent are placed. This difference is recognized in grading, and the variety is recommended for distribution in a more eastern area.

Table 3 presents the reported yields upon which registration was based.

TABLE 3.—*Comparative yields of Coronation and standard hard red spring wheats grown in nursery (six replications) experiments at various stations in western Canada.*

Variety	1934	1935	1936	1937	1938	Average	Percentage of Marquis
Number of stations	1	1	12	14	1		
Coronation (new)......	42.3	17.0	19.8	23.5	26.4	25.8	179.1
Ceres (standard)	31.0	3.3	18.8	21.5	8.8	16.7	116.0
Marquis (standard)....	24.1	3.3	17.4	19.9	7.5	14.4	100.0

REGENT, REG. NO. 327

Regent (C. A. N. 1902; R. L. 975.1; C. I. 11869) was developed from a cross between H-44 and Reward made in 1926 at the Dominion Rust Research Laboratory, Winnipeg, Canada. Like Renown and Coronation, it is a product of the Dominion Experimental Farms System. The superior characters reported for Regent are high yield, medium early maturity, and resistance to stem rust, leaf rust, and bunt. It has awnleted spikes, white glabrous glumes, and mid-long red kernels. Strain R. L. 975 was first selected in 1928, reselected in 1932, tested from 1934 to 1938, and distributed in the spring of 1939. The yields reported upon which registration was based are given in Table 4.

TABLE 4.—*Comparative yields of Regent and standard hard red spring wheats grown in nursery (six replications) experiments at various stations in western Canada.*

Variety	1934	1935	1936	1937	1938	Average	Percentage of Marquis
Number of stations.....	1	1	12	14	15		
Regent (new)..........	40.6	20.8	17.3	24.9	30.8	26.9	159.2
Ceres (standard).......	31.0	3.3	18.8	21.5	22.5	19.4	114.8
Marquis (standard)....	24.1	3.3	17.4	19.9	19.8	16.9	100.0

For further information on Renown, Coronation, and Regent wheats see Handbook of Canadian Spring Wheat Varieties, by L. H. Newman, J. G. C. Fraser, and A. G. O. Whiteside. Canada Dept. Agr. Pub. 538, 54 pages. March, 1939.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, IX[1]

T. R. STANTON[2]

THE eighth annual report (6)[3] on the registration of improved varieties of oats was published in December, 1938. During 1939 five varieties were submitted and approved for registration. They are as follows:

Group and Varietal Name	Reg. No.
Early yellow:	
Boone	87
Hancock	88
Early white:	
Marion	89
Midseason red:	
Fulwin	90
Tennex	91

Information on the origin, development, description, performance, and probable agronomic value of these new varieties on which approval for registration is based, is summarized in the paragraphs below.

BOONE, REG. NO. 87

Boone (C. I. 3305)[4] was originated from a cross (No. XS1098) between Victoria and Richland, made by the writer in the greenhouse at the Arlington Experiment Farm, Arlington, Va., in 1930. This cross was made to introduce the crown rust and smut resistance of the Victoria variety into Richland type oats. Information on the growing and handling of this cross has been published (5, 7, 8).

Boone was developed cooperatively by the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Those besides the writer who had a part in the development of Boone are H. C. Murphy, F. A. Coffman, L. C. Burnett, and H. B. Humphrey. The group of selections from which Boone was originated also was grown in certain years at the Aberdeen Substation, Aberdeen, Idaho, in the greenhouse at the Arlington Experiment Farm, Arlington, Va., and at the Brooklyn Botanic Garden, Brooklyn, N. Y., under the supervision of Harland Stevens, John W. Taylor, and George M. Reed, respectively. Application for the registration of Boone was made by the writer at the request of the Seed Distribution Committee of the Iowa Agricultural Experiment Station.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 9, 1939.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, member of the 1939 Committee on Varietal Standardization and Registration charged with the registration of oat varieties.

[3]Reference by number is to "Literature Cited", p. 82.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

Boone is classified as an early yellow common oat, with short, stiff straw like that of the Richland parent and plump kernels with few awns. Its superior characters are early maturity, high yield and quality, and high resistance to nearly all physiologic races of stem rust, crown rust, and the smuts of oats. Boone was tested in a 15-foot row in 1935 and in replicated plats from 1936 to 1939 in the cooperative experiments at Ames and Kanawha, Iowa. The data obtained are shown in Table 1.

For data on the yield of Boone at experiment stations in other States, and for further information on its high resistance to disease, the reader is referred to published articles (5, 7, 8) and to mimeographed reports.[5]

Boone will be distributed to farmers of Iowa for growing in 1940.

HANCOCK, REG. NO. 88

Hancock (C. I. 3346) was originated from a cross (No. X2871) between Markton and Rainbow oats made in the greenhouse at the Arlington Experiment Farm by F. A. Coffman in 1928. The F_1 plants were grown at the Aberdeen Substation in 1928, the F_2 generation was grown in the greenhouse at Arlington Farm in the winter of 1928–1929, and the F_3 to F_5 generations were grown en masse at Ames, Iowa, from 1929 to 1931. Information on the group of selections from which Hancock was derived has been published (1).

Hancock was developed cooperatively by the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, at Ames, Iowa. Those having a part in the breeding of Hancock, besides F. A. Coffman, are H. C. Murphy, T. R. Stanton, L. C. Burnett, and H. B. Humphrey. The group of selections giving rise to Hancock also was grown in certain years at the Aberdeen Substation under the supervision of L. L. Davis and Harland Stevens, and in the greenhouse at Arlington Farm under the supervision of John W. Taylor. Application for the registration of Hancock was made by F. A. Coffman at the suggestion of the Seed Distribution Committee of the Iowa Agricultural Experiment Station.

Hancock is an early common yellow to yellowish white oat with tall very stiff culms and plump kernels with relatively few awns. The superior characters of Hancock are early maturity, good quality, exceptionally stiff straw that resists lodging, and resistance to stem rust and to most physiologic races of loose and covered smut. Hancock is primarily a special purpose variety for growing with and combining over newly-sown stands of sweet clover. Hancock was tested in repli-

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[5]BURNETT, L. C. Information from experiments in progress, small grains summary. Iowa Agr. Exp. Sta. Leaflet F. C. 10. Jan. 1939. [Mimeographed.]

COFFMAN, F. A. Results from the cooperative, coordinated oat-breeding nurseries for 1938 and the uniform winter hardiness nurseries for 1938–39, together with average for previous years. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases [Unnumb. Pub.] 100 pp. July 15, 1939. [Mimeographed.]

STANTON, T. R. Disease-resistant oat varieties. U. S. Dept. Agr., Ext. Path. Serial No. 39, 70–71. August 1939. [Mimeographed.]

cated plats at Ames and Kanawha, Iowa from 1935 to 1939. The yields of Hancock, compared with those of Iogold and Richland, standard varieties in Iowa, are shown in Table 2.

For yields of Hancock and Marion in other states and for additional information on its disease resistance, see Coffman, *et al.* (1), and also special mimeographed reports.[6] Hancock was increased in 1939 for distribution to farmers of northern Iowa in 1940.

MARION, REG. NO. 89

Marion (C. I. 3247), like Hancock, was originated from the Markton-Rainbow cross (No. X2871) made by F. A. Coffman at Arlington Farm in 1928. The selection, testing, and disease resistance of Marion have been reported (1). Marion is a product of the cooperative oat improvement program of the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Among those having a part in the breeding of Marion besides F. A. Coffman are H. C. Murphy, T. R. Stanton, L. C. Burnett, and H. B. Humphrey. The group of selections from which Marion was originated also was grown in one or more years at the Aberdeen Substation under the supervision of L. L. Davis and Harland Stevens, and at the Arlington Farm under the supervision of John W. Taylor. Application for the registration of Marion was made by F. A. Coffman at the suggestion of the Seed Distribution Committee of the Iowa Agricultural Experiment Station.

Marion is an early to midseason yellowish white to white common oat with midtall to tall plants, a stiff straw, and plump kernels with relatively few awns. Marion is a white oat obtained by crossing two yellow varieties. The superior characters of Marion are early maturity, high yield, and high test weight, with kernels of the best type for milling and for feed. It also has stiff straw and resistance to stem rust and smut, as well as resistance to certain races of crown rust. Marion has been grown in replicated plats at Ames and Kanawha, Iowa from 1935 to 1939. The yields of Marion and of Iogold and Richland, standard Iowa varieties, are given in Table 2.

FULWIN, REG. NO. 90

Fulwin (C. I. 3168 and Tenn. No. 1945) was originated as a reselection from Fulghum (winter type, sel. 699–2011 and C. I. 2499) by Newman I. Hancock at the Tennessee Agricultural Experiment Station, Knoxville, Tenn. Mr. Hancock submitted the following notes on origin with the applications for the registration of Fulwin and the sister variety, Tennex, discussed later:

"*History.*—In the crop year 1929–30 it was observed that Fulghum, sel. 699–2011, was very winter hardy, but that it contained many off-type plants. A thousand head or panicle selections were made and sown in rows 39 inches long in the fall of 1930. Around two thousand panicle selections again were made during the harvest of 1931 and sown the following fall. * * *

[6]See footnote 5.

TABLE 1.—*Yields of Boone, Iogold, and Richland (Iowa 105) oats grown at Ames and Kanawha, Iowa, 1935–39.*

Variety	Acre yield, bushels											
	1935, Ames	1936		1937		1938		1939		Averages		
		Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames and Kanawha*
Boone	89.0	76.0	85.0	96.8	102.3	70.6	70.0	44.7	79.9	75.4	84.3	79.4
Iogold	60.5	78.6	70.7	75.2	74.7	37.8	27.8	46.2	69.5	59.7	60.7	60.1
Richland	58.1	67.0	78.3	77.2	78.9†	41.9	37.2	44.7	65.4	57.8	65.0	61.0

*Average of 9 station years.
†Estimated yield.

TABLE 2.—*Yields of Hancock, Marion, Iogold, and Richland (Iowa 105) oats at Ames and Kanawha, Iowa, 1935–39.*

Variety	Acre yield, bushels												
	1935		1936		1937		1938		1939		Averages		
	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames and Kanawha*
Hancock	53.5	62.5	66.0	79.3	93.8	79.3	48.7	65.4	45.3	68.9	61.5	71.1	66.3
Marion	49.5	90.4	76.6	92.7	101.6	97.3	46.6	70.9	54.1	79.9	65.7	86.2	76.0
Iogold	46.9	59.9	70.3	62.1	67.2	74.5	37.8	27.8	46.2	69.5	53.7	58.8	56.2
Richland	62.0	62.1	55.0	67.0	69.0	79.7†	41.9	37.2	44.7	65.4	54.5	62.3	58.4†

*Average of 10 station years.
†Estimated yield.

"Seed was saved from the best strains of 1931–32 which were grown in rod rows. * * * The best strains or rows were again saved and * * * were sown in rod rows * * * the third crop year. In the following crop years larger plats were used, * * * Tenn. Nos. 1945 and 1884 originating from the 945th and 884th panicle rows of 1930–31, respectively.

"Fulghum sel. 699–2011 was originated by T. R. Stanton, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. Agriculture, from whom it was received by the Tennessee station in the fall of 1929."

For further detailed information on the origin of sel. 699–2011, see Stanton (4). The following description of Fulwin was submitted by Mr. Hancock with the application for registration:

"*Description.*—Culms slightly hairy at the nodes, midsized, tendency to lodge if planted too thick; 90 to 120 cm long. Sheaths light green, slightly hairy or glabrous. Culm leaves midwide, margins slightly hairy at basal portions. Peduncles slender, straight, ascending, well exserted, 25 to 35 cm long. Panicles erect, equilateral, very long, open and spreading. Rachises with 5 to 7 nodes, branches short to long, ascending, scabrous, a whorl of 2 to 7 branches at each node. Spikelets few to numerous, 2-flowered, sometimes 3-flowered; usually separating from their pedicels by fracture; kernels slender to mid-plump. Glumes 20 to 25 mm long, 6 to 8 mm wide, 9- to 11-veined, light green before maturity. Lower lemmas 16 to 18 mm long, reddish yellow at maturity; basal hairs few or absent; awns few to common, straight, scabrous. Basal hairs few or absent at callus. Upper lemmas 12 to 15 mm long, reddish yellow at maturity. Rachilla segment 2 to 2½ mm long, nearly glabrous; articulates with upper grain in most instances."

The superior characters of Fulwin are winter hardiness, high yield, vigorous, tall plants, and suitability for late seeding after corn is harvested in Tennessee. Fulwin has been tested in replicated nursery rows and field plats at Knoxville. The yields of Fulwin and of standard and other varieties are given in Table 3.

TABLE 3.—*Yields of Fulwin, Tennex, and other varieties of winter oats grown at Knoxville, Tenn., 1934–38.*

Variety	Acre yield, bushels						
	1934	1935	1936*	1937	1938	Averages	
						1934–38	1935–38
Fulwin	51.2	43.1	19.1	87.0	46.0	49.3	48.8
Tennex	48.6	42.2	16.5	86.0	48.5	48.4	48.3
Winter Turf	33.8	22.6	2.8	54.8	36.1	30.0	29.1
Fulghum (sel. 699–2011)	39.6	37.1	7.4	61.5	—	—	36.4†
Lee	—	28.8	6.3	75.1	48.3	—	39.6
Coker 32–1	—	24.7	2.5	62.9	41.7	—	33.0

*Low yields due to a heavy infestation of plant lice in the fall, followed by severe injury by freezing to the weakened seedlings that remained.
†Average 1934–37.

TENNEX, REG. NO. 91

Tennex[7] (C. I. No. 3169 and Tenn. No. 1884) is a sister strain of Fulwin having been originated from Fulghum (winter type sel. 699-2011 and C. I. 2499) by Newman I. Hancock at the Tennessee Agricultural Experiment Station, Knoxville, Tenn., who also made application for its registration.

Tennex is similar to Fulwin in nearly all plant characters. It differs from Fulwin only in having darker green leaves in the seedling stage and in flowering a week to 10 days earlier. The grains also are slightly smaller and have stronger awns, some of which are twisted and subgeniculate.

The superior characters of Tennex are winter hardiness, high yield, and early maturity. It ripens from two to three weeks earlier than Winter Turf and 10 days earlier than Lee at Knoxville. Like Fulwin, it also is more satisfactory for late seeding after corn than these older varieties. Tennex has been tested in replicated nursery rows and field plats at Knoxville. Yields of Tennex and of standard and other varieties of oats at Knoxville are given in Table 3.

Yield data on Fulwin and Tennex and other varieties at Knoxville, Jackson, and Columbia, Tenn., are shown in Table 4.

TABLE 4.—*Yields of Fulwin, Tennex, and four other varieties of winter oats grown from early and late seeding at Knoxville, Jackson, and Columbia, Tenn.*

Variety	Acre yield, bushels					
	Knoxville			Jackson		Columbia
	Average 1934 to 1938, early seeding	1938		Average 1937 and 1938, early seeding	1938, early seeding	1938, late seeding
		Early seeding	Late seeding			
Fulwin	49.3	46.0	38.3	79.2	75.8	25.0
Tennex	48.4	48.5	40.7	80.0	81.7	34.4
Fulghum (sel. 699-2011)	36.4*	—	—	—	—	—
Winter Turf	30.0	36.1	—	45.4	43.3	17.2
Lee	39.6†	48.3	11.4	61.7‡	61.7	—
Coker 32-1	33.0†	41.7	34.5	63.8	57.5	13.3

*Four-year average, 1934-37.
†Four-year average, 1935-38.
‡Yield for 1938 only.

Data on relative winter hardiness of Fulwin, Tennex, and on other varieties, submitted by Mr. Hancock, are shown in Table 5.

[7]The official spelling has been changed recently by the Tennessee Agricultural Experiment Station from "Tenex" to "Tennex."

TABLE 5.—*Average hardiness indexes of Fulwin, Tennex, and four other varieties of winter oats when tested in cold chambers at the Iowa Agricultural Experiment Station, Ames,* 1933–34 and 1934–35, and in nurseries at 28 experiment stations in the United States in the crop years 1936–37 and 1937–38.*†

Variety	Average survival							
	In cold chambers				In uniform nurseries			
	1933–34		1934–35		1936–37		1937–38	
	%	Rank‡	%	Rank‡	%	Rank§	%	Rank¶
Fulwin	75.0	6	73.1	3	92.8	1	76.1	1
Tennex	74.2	7	68.3	7	91.9	2	75.6	2
Hairy Culberson	—	—	68.2	8	90.3	4	71.3	7
Winter Turf	—	—	60.0	11	86.6	12	67.6	14
Fulghum (sel. 699–2011)	—	—	53.1	20	88.4	9	71.4	6
Coker 32–1	—	—	57.8	13	87.9	10	70.1	11

*Results of cooperative experiments conducted by H. C. Murphy of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U S Dept. of Agriculture, and the Iowa Agricultural Experiment Station. For more complete data see Murphy (3).

†Coffman, F A. Results from the cooperative, coordinated oat-breeding nurseries for 1937 and the uniform winter-hardiness nurseries for 1937–38, together with average for previous years. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases [Unnumb. Pub.] 108 pp. May 28, 1938. [Mimeographed.]

‡Data from 35 varieties and selections in 1933–34 and in 1934–35.

§Data from 28 varieties.

¶Data from 30 varieties.

For further information regarding the development of Fulwin and Tennex oats, see the forty-ninth annual report of the Tennessee Agricultural Experiment Station (9, page 10), and special articles by Elliott (2) and Hancock.[8]

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[8]HANCOCK, N. I. New Tennessee winter oats. Tenn. Agr. Exp. Sta. Circ. of Inform. 47, 2 pp. July 22, 1939. [Mimeographed.]

REGISTRATION OF IMPROVED COTTON VARIETIES, II[1]

H. B. BROWN[2]

THE first report on the registration of improved cotton varieties was published in December 1936.[3] No varieties were registered in 1937 or 1938. An application for registration was received in 1938, but it was not submitted and approved until 1939. This variety was named Texacala and given Registration No. 35. Below is a brief description of the variety.

TEXACALA, REG. NO. 35

Texacala, formerly known as Rogers Acala 111, originated from a plant selection made near Navasota, Texas, in 1924 by J. H. McDonald, who is plant breeder for the John D. Rogers Seed Company, Navasota, Texas. The parent stock of this variety was secured from D. A. Saunders in 1921. Saunders assisted in the acclimatization of this cotton after its importation from Mexico some years previously. Following the selection, the strain was subjected to self-fertilization, roguing, and re-selection. This resulted in a strain of very uniform type. It is characterized by excellent productivity, especially under slightly arid conditions, and the very desirable combination of good lint percentage and good staple length. It is grown extensively in Texas and has been introduced in Mexico, Greece, and Ecuador.

Under good growing conditions, the plants attain a height of 3 to 5 feet; vegetative branches are few; fruiting branches are long on the lower part of the plant but short on the upper part, thus producing a cone-shaped plant; leaves medium sized, dark green; bolls short-pointed, snub-nosed type—66 to 78 per pound; staple length, 1/32 to 1⅛ inches; percentage lint 34 to 38; seeds medium size, 3,600 per pound; lint index 7.6 to 8.2; somewhat earlier than other of the Texas big boll varieties.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 30, 1939.

[2]Agronomist, Louisiana Agricultural Experiment Station, University, Louisiana, and a member of the 1939 Committee on Varietal Standardization and Registration, charged with the registration of cotton varieties.

[3]BROWN, H. B. Registration of improved cotton varieties, I. Jour. Amer. Soc. Agron., 28:1019–1020. 1936.

BARLEY VARIETIES REGISTERED, V[1]

H. K. HAYES[2]

ONE variety of barley was approved for registration in 1937[3] making seven varieties registered previous to this report. One variety was approved for registration in 1939.

REX, REG. NO. 8

Rex is a lax, six-rowed, hulled, smooth-awned barley with high yielding ability, early maturity, and high bushel weight produced at the University of Saskatchewan, Canada, by Dr. J. B. Harrington from a cross of Velvet with Hannchen. It was first distributed for sowing in 1939.

Comparative yields of Rex and four other varieties are given in Table 1.

TABLE 1.—*Comparative yields on summer fallow at Saskatoon, Sask., in rod-row plots with six replications randomized.*

Variety	Average yield in bushels per acre					
	1934	1935	1936	1937	1938	Average
Rex, Sask. 1761 . . .	48.4	41.2	23.5	2.6	29.1	29.0
Hannchem, Sask. 229	44.8	40.7	20.4	8.9	24.5	27.9
Trebi, Sask. 101	46.6	51.2	18.7	5.4	17.5	27.9
Regal, Sask. 1865 . .	48.2	41.7	14.1	3.1	20.5	25.5
O. A. C. 21, Sask. 228	39.0	26.6	10.2	1.9	15.0	18.5

TABLE 2.—*Agronomic characters of Rex and four other varieties on summer fallow 1934–38, inclusive, Saskatoon, Sask.*

Variety	Height of plant, cms	Straw strength, %	Days seeding to ripe	Weight in lbs. per bu.	1,000 kernel weight, grams
Rex.	65	95	80	52.3	34.0
Hannchen	60	91	83	52.9	30.3
Trebi	57	92	79	44.5	34.8
Regal	66	98	82	48.6	28.8
O.A.C. 21	63	91	81	45.3	26.0

Comparison of agronomic characters of Rex and other varieties are given in Table 2. Rex excels Hannchen in length and strength of straw, matures earlier, and is equal to Hannchen in yield and bushel weight of grain.

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[1]Registered under the cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 4, 1939.

[2]Chief, Division of Agronomy and Plant Genetics, Department of Agriculture, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of barley varieties.

[3]HAYES, H. K. Barley varieties registered, IV. Jour. Amer. Soc. Agron., 29: 1032–1033. 1937.

BOOK REVIEWS

ECOLOGY OF FIELD CROPS (ECOLOGIE AGRICOLE)

By J. S. Papadakis. Edited by Jules Duculot, Gembloux, Belgium, in Bibliotheque Agronomie Belgae. Paris: Librairie Agricole de la Maison Rustique. XV+312 pages, illus. Paper bound. 1938.

THE word "agricultuer" is used here in its literal meaning of cultivation of field crops. Although most farm products which would be included under agronomy are considered, major attention is given the small cereals. After a discussion of general principles, the developmental periods of plants are considered in relation to long and short periods of flowering, temperature, and length of day. A classification of crop plants from the point of view of developmental periods is given.

Various ecological factors are treated in considerable detail in about one-fourth of the book. These factors include water relations, snow, climate, phytosociology, cultivation, and soil in relation to climate, illustrated by a map of the world showing the distribution of 12 kinds of climatic soils and smaller maps of these soils in Europe and the United States.

In the chapter "Ecology of the Small Grains" is an extended table showing dates of earing observed by the author in tests with numerous varieties of wheat, rye, barley, and oats planted at different times in various parts of Greece. Several chapters are devoted to the ecology of a number of non-cereal crops.

About one-fifth of the volume is devoted to the chapter "Ecological Classification of Climate". The climates in which field crops are grown have been divided into 43 types grouped under five belts. Each type is discussed briefly as regards temperature, precipitation, and influence on various crops. Data regarding 92 stations throughout the world are given in tables and in graphs. The latter show monthly mean temperature, rainfall, and soil moisture in excess or below plant requirements. A map of the world shows the distribution of the zones and types of climates.

The text and tables contain information on soil types accompanying climatic types, climax vegetation, and relative influence of climate on the development of cereals and other crops. In one chapter, the methods of ecological research are considered, including a short discussion of statistical methods and plat technic. The final chapter is devoted to crop improvement through genetics and adaptation of plants to suitable environments. The citation of literature includes 167 entries many of which are by foreign authors.

The book is well written in French that is not difficult to translate. The author has brought together a wealth of information, but his analysis of the subject matter and his contributions from his experiments constitute a valuable part of the book. The numerous maps and diagrams enhance the value of the work. While soil and climate have been treated from a world-wide viewpoint, special consideration of the various crops have been restricted largely to the United States

and Europe. The book should prove an excellent text for those interested in the geography and ecology of crop plants. (F. Z. H.)

SOIL CONSERVATION

By Hugh Hammond Bennett. New York: McGraw-Hill Book Co., Inc. XVII+993 pages, illus. 1939. $6.

FOR more than 30 years Hugh Hammond Bennett has been a persistent champion of soil conservation. Here at long last is a book from his pen sufficiently broad in scope to represent in technical literature the personal achievements of the author. But the book is in no sense an autobiography. Against a background of the history of soil destruction in the United States and throughout the world, it presents a wealth of factual information that gives perspective to the whole involved problem of land use, and brings into sharp focus the urgent necessity of a national program of soil conservation to counteract the rapid depletion of our soil resource.

"Soil Conservation" discusses the rates at which soils are being destroyed by misuse, and emphasizes the relationship of erosion and water wastage to flood control, sedimentation, agricultural impoverishment, and the inevitable subsequent sociological and economic problems. Measures for soil defense and reclamation are presented, together with means for putting a national soil conservation program into effective operation. For many, the chapter on a national program of soil conservation will prove to be the most important one in the text.

As climate and type of agriculture vary from one section of the country to another, the erosion problem is also modified. Perhaps no one is more familiar with the local and regional aspects of the problem than is Hugh Bennett. In "Soil Conservation", one finds descriptions of specific problem areas, within the confines of which there are characteristic conditions of soil erosion and land use. This geographic analysis of the national problem should direct the attention of readers to the necessity of specific knowledge in the application of control or regulatory measures.

To detail further the contents of the book is useless. The book has an encyclopaedic quality that is impossible to characterize by a mere listing of contents. Over a period of years many workers have contributed to the literature on soil erosion by wind and water. These prior writings have been drawn upon to furnish illustrative data to show the extent of the erosion problem, and the adequacy of available and practical methods of control. If, as the author suggests, a limitation of space has necessitated the omission of much material pertinent to a complete treatise, the reviewer can add only that selection has been comprehensive enough to develop completely the major thesis of the science and practice of soil and water conservation.

The book is attractive in appearance, on good paper, profusely and well illustrated. (C. S. S.)

AGRONOMIC AFFAIRS

A NEW EDITORIAL BOARD FOR THE JOURNAL

COMPLYING with the recommendations of the Editorial Advisory Committee made to the Society at the annual meeting in New Orleans, La., November 23, 1939, and adopted by unanimous vote, the Executive Committee elected J. D. Luckett, Editor; Dr. Ralph J. Garber, Associate Editor in Crops; and Professor Emil Truog, Associate Editor in Soils, for the year 1939-40.

As heretofore, all papers to be submitted for publication in the JOURNAL should be directed to the Editor at the New York State Experiment Station at Geneva. The Editor will in turn refer all crops papers to the Associate Editor in Crops and all soils papers to the Associate Editor in Soils. Each of the Associate Editors has named a corps of Consulting Editors which will serve as a review board for papers in their respective fields. These two groups are as follows:

Consulting Crops Editors, Dr. H. K. Hayes, University of Minnesota; Dr. M. T. Jenkins, U. S. Dept. of Agriculture; Dr. R. D. Lewis, Ohio State University; Dr. L. F. Graber, University of Wisconsin; and Dr. Ide P. Trotter, Texas A. & M. College.

Consulting Soils Editors: Dr. G. B. Bodman, University of California; Dr. I. L. Baldwin, University of Wisconsin; Dr. W. H. Pierre, Iowa State College; and Dr. L. D. Baver, Ohio State University.

This new Editorial Board, which replaces the Editorial Advisory Committee, has already begun to function and is confidently expected to strengthen materially the editorial supervision of the JOURNAL.

STUDENT SECTION ESSAY CONTEST FOR 1940

STUDENTS presenting the best papers in the Student Section essay contest sponsored by the Society will receive awards as follows: The first three winners receive expense money to enable them to attend the International Grain and Hay Show in Chicago. The total allotment for the three will not exceed $150.00. The amounts granted may vary with the distance the winners are from Chicago. For example, if a Wisconsin student won first and an Oregon student second, it would be desirable to grant a larger amount to the Oregon student, as his expenses would be greater. The committee reserves the right to adjust this as conditions warrant. In addition, the three high men will receive appropriate medals and a year's subscription to the JOURNAL of the American Society of Agronomy.

The winners of the fourth, fifth, sixth, and seventh places will receive cash awards of $20, $15, $10, and $5, respectively.

All essays must be prepared by undergraduate students. Students graduating during the course of the 1939-40 school year or those graduating during the summer school of 1940 are eligible, providing their papers are submitted before graduation. A certification of

eligibility to qualify as an undergraduate, signed by the dean of the college, must accompany each paper.

Papers should be typed, double spaced and not less than 3,000 or more than 3,500 words in length. *Abstracts of not more than 500 words must accompany each paper.* Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify the paper.

The title for the essay shall be "Causes of Run-down Pastures and Methods of Their Improvement". The subject may be treated for any section or all sections of the United States and from any angle.

All papers are to be submitted in duplicate and if it is desired that the essay be returned, postage should be enclosed.

The committee suggests, that where several papers are entered from a given institution, the local representatives of the Society review the essays and submit only the best articles. This will save work for the committee and reduce mailing expenses. Usually not more than five papers should be submitted from one institution for final review by the committee. The winners of the contest will be announced at the meeting of the American Society of Agronomy in Chicago in November, 1940, and the results published in the December 1940 issue of the JOURNAL.

Essays must be in the hands of the chairman of the committee, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than August 1, 1940.

EIGHTH AMERICAN SCIENTIFIC CONGRESS

THE eighth American Scientific Congress will be held in Washington, D. C., May 10 to 18, 1940, under the auspices of the United States government. Invitations have been extended to governments members of the Pan American Union to participate in the Congress and scientific institutions and organizations are also invited to send representatives.

The Congress will be divided into the following sections: Anthropological Sciences, Biological Sciences, Geological Sciences, Agriculture and Conservation, Public Health and Medicine, Physical and Chemical Sciences, Statistics, History and Geography, International Law and Public Law and Jurisprudence, Economics and Sociology, and Education. Chairmen of the respective sections will be named at an early date.

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THE SOCIAL AND ECONOMIC PROBLEMS OF SOUTHERN AGRICULTURE[1]

W. C. LASSETTER[2]

WE are happy to welcome the American Society of Agronomy to the South where we have social, economic and agronomic problems. We are highly honored by your presence.

Before starting it might be well to define the area to which we shall refer as the South. For convenience we are letting this area begin with Virginia and West Virginia to the northeast, Kentucky to the North, and extend across all of the states of the southeast and including Arkansas, Oklahoma and Texas in the southwest. This forms an area comprised of fourteen states more commonly known as the South.

To understand better some of the social and economic problems of the South you may need to know more about the South itself. It is a country of sharp contrasts. In soils it has the blackest and the whitest. In population the whitest and the blackest. And in each case all gradations in between. In the great Mississippi Delta area we have gathered some of the richest of all soils contributed by the farms of Pennsylvania and Ohio, Montana and the Dakotas, and the great basin in between. You may be interested to know your Northern soils concentrated in our Mississippi Delta grow the whitest and finest of cotton and the sweetest of sugar cane. When we thought our deltas were rich enough we built levies so that the less rich land you are now sending down is being dumped into the Gulf of Mexico. While these vast delta areas have been busy receiving the best soils the country afforded, scarred hillsides in other parts of the South have been equally as busy giving up the best they had.

Farm lands over certain vast areas in the South lie in large, level or rolling fields in such condition that they can be worked with the most modern of farm machinery. In sharp contrast we have other vast areas where fields are small and slopes so steep that their cultivation is accomplished only with greatest difficulty. In size, farms vary from the proverbial one-horse farm of the old cotton belt, an

[1]Presented on the general program of the thirty-second annual meeting of the Society held in New Orleans, La., November 23, 1939.
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area too small in many sections to permit a family to do better than eke out a bare living, up to the larger plantation where in some instances hundreds of families are required to carry on the business of the place.

If we were to confine ourselves to the line of attack that seems to be most popular nowadays we would devote our entire time this morning to picturing the very worst that could be found in our social and economic setup. A few years ago this country was engulfed with articles galore telling of the terrible conditions prevailing in the slums and tenament sections of the larger cities of the North. Today's pasttime seems to be the writing of articles and the printing of pictures taken in corresponding slum areas of the rural South. We would have no objection to this except for the fact that many of our friends may get the impression that there is little else in the rural South. How quickly people jump to false conclusions may be illustrated as follows: A few years ago the city of Miami was struck by a tropical storm that did considerable damage. The news of the storm was heralded far and wide. A few weeks later when I remarked to a friend in Nebraska that I had to be in Jacksonville on the following Monday, he turned quickly and said with apparent surprise, "Why! I thought Florida was destroyed by the storm." It's true the storm did a great deal of damage but it barely came within 400 miles of Jacksonville and certainly all Florida lacked a lot of being destroyed. Likewise, in all of the current stories on the privation suffered by certain people in the rural South who can be found and who can be induced to pose for pictures, we trust you will not jump to the conclusion that all the South is like that.

Has it ever occurred to you that the South has more than half of the farm population of the United States? According to the 1935 census the farm population of the South totaled slightly more than sixteen million people or fifty-two per cent of the full farm population of the United States. This large farm population as compared with the rest of the United States has come about for three reasons: (1) The agriculture of the South has been built up largely on what we can characterize as a hand labor basis, which system requires more people in proportion to the cultivated acreage, (2) The South has not had the industries that the North has had to take up the surplus of farm labor, (3) as the saw mills exploiting the South's wonderful stands of virgin timber cut out and abandoned their mills there was nothing for their labor to do but take up small farms on these cut-over lands.

Over a period of many years the South's major production lay in the line of cotton and tobacco, with some scattering development of orchards and truck crops. Each of these crops has the capacity to produce a comparatively high income per acre. As a result human labor could be profitably employed on a next to hand labor basis. One horse plow, one horse cultivator, common garden variety of hoe—all of these barely one step in advance of hand labor. As a result the family worked only a small unit of land. So long as prices were such that the income per acre was good the family was able to meet its modest living requirements on this small acreage.

The same equipment used for the production of cash crops naturally was used for the production of feed crops. But here the cost mounted out of proportion because the return per acre from these crops is in no sense as large as the return per acre from the more important cash crops. As a result farmers of the South could not be induced to diversify their crops and produce more of the things they consumed on the place for the reason that on a hand labor basis the cost of producing these things was out of proportion to the value of the crop produced. So long as prices of their cash crops continued favorable there was little inducement to change from this practice. It is a fact, however, that here and there progressive farmers began to see the light and began to modify their system by the introduction of such improved machinery as they could without serious derangement of their farming activities.

The period from 1930 to 1933 brought the crisis. Heretofore, land owners had been able to make the necessary advances to their tenant families and the prices of crops were such that the tenant family, even though it worked only a small acreage, was able to repay these advances in the fall in most years and be prepared to start out the new year with a clean slate. With the disasters of 1930, 1931, and 1932 this situation changed. Tenants could no longer repay their advances. Land owners reached the point where they no longer could make advances because their own resources were strained to the vanishing point. As one large farmer told me in the spring of 1934, "When the depression started I had $40,000 in the bank. By midsummer in 1933 I was $40,000 in debt. I had 90 families on my place to take care of."

For many, many years as pointed out above labor in the South was cheaper than machinery. By 1931 and 1932 a point had been reached where machine labor was cheaper than man labor. For example, back about 1918 or 1919 I visited a large plantation in the Arkansas Delta. The county agent had been urging this man to add some improved machinery in order to make certain improvements in his management. The land owner took us out. We drove through a a thousand acre field that was being planted to cotton with cheap ponies, one-horse plows, the cheapest of gear. Beyond this field we approached a 500 acre tract where the under-brush had been removed and large trees had been deadened. Weaving back and forth among the deadened trunks again were more light ponies, more cheap harness, more small plows. Pointing to this tract the owner remarked, "this land is making me $15.00 per acre. What do I want with your machinery?"

There came a time when the labor so employed by this man could no longer pay for its advances and the owner was put to it to find ways and means whereby he could provide a living wage for the people he was obligated to take care of. Under such conditions owners were forced to turn to machinery to replace labor that could not make its wage. This movement has become so extensive that today we are going through what may well be called a revolution in the agricultural South.

When you begin to replace men with machinery you have in effect a revolution, whether there is bloodshed or not. You may recall from your history what took place in England when the machinery for textile mills was invented and work that once had been done in the homes of the workers on small improvised looms and spinning wheels was taken to the factories and thousands and thousands of people were thrown out of work. Your history tells of the rioting that followed. Today we are going through a similar change without rioting because up to the present time it has been sufficiently gradual to permit of some readjustment, enough readjustment to keep people from actually going hungry.

Northern labor centers have helped by taking hundreds of thousands of southern workers. Many thousands of farm workers of the South have found some sort of living, such as it is, in the cities of the South. But the rural South is still confronted with a population problem, the problem of providing a way for its millions of people to earn a better livelihood.

For many years farmers of the South could not take advantage of improved machinery to increase their production of cotton with less labor for the reason that labor was necessary in harvesting the crop. In order to have the labor at hand during the harvest season they had to provide employment at other times of the year. Therefore, they continued on a hand labor basis as long as hand labor could make its wage.

Mechanical cotton pickers have been developed on an experimental basis but none has yet been developed to the point where farmers are taking to it and utilizing it. This situation now, however, is being obviated in part by transient labor. California knows the meaning of transient labor. Our strawberry sections have known the employment of transient labor for many years. Texas and Oklahoma have been utilizing transient labor in the harvest of cotton in recent years and now the movement has extended as far East as the Mississippi Delta. The heralded labor troubles in southeast Missouri this past year came about largely in connection with transient labor that had gone into this territory to pick the cotton crop and then was left stranded.

Regardless of what we think is right and wrong, regardless of what we think is the necessary adjustment, there is now a strong and definite move toward the use of more machinery on southern farms. In the necessity for limiting the acreage of cotton in order that production might be more nearly in line with that which could be marketed land necessarily was released. Other crops with a per acre value large enough to permit production on a hand labor basis were not available. To utilize this land, to make it help pay the overhead expense of the farm, machinery had to be introduced so that more acres per family could be worked, so that the family could have the benefit of the return from more acres of land.

To show how rapidly this movement is advancing one probably can best turn to sales figures on tractors in the South. In the state of Virginia where there long has been considerable livestock development and where tobacco is of greater importance than cotton, the number of tractors from 1930 to 1938 increased by only 32%. In

North Carolina where livestock has not occupied the place that it has in Virginia and where cotton is a more important factor the number of tractors has increased by 72%. In South Carolina where similar conditions prevail the increase has been 73%. Coming down to Georgia the increase has been 99%; in Alabama, 92%. And when we strike the great cotton producing state of Mississippi with its rich delta soils and large areas admirably suited for tractor farming we find that the number of tractors has increased by 165%. Arkansas and Louisiana follow closely with 126% and 118%, respectively, while in Texas the number of tractors in the same period jumped from 37,000 to 99,000, or 165%.

What effect does this have on the social and economic problem of the South? Remember the agriculture of the old South was a one man, one mule system—when you replace a mule you replace a man. A friend of ours on a rolling farm in Alabama was showing us an all purpose tractor. "I sold six mules", he remarked, "and bought this tractor. I took a club-footed negro who could not follow a plow and taught him to operate the tractor. He can ride the tractor and cultivate 30 acres of cotton a day." "What became of the six families that were replaced", I asked. "Oh! They found places around here", he answered.

I stepped on to a farm machinery floor in Atlanta. The manager came out and pointed to a large tractor with fertilizer and cultivator equipment and remarked, "the man who buys this tractor can sell fifteen mules." Again, one could not help but think what is to become of the families that it displaced.

Some farmers are buying improved equipment and are able to work out a plan of operation that permits the use of this equipment for the benefit of all the families on the place. Other places over populated even on a hand labor basis can hardly do so well.

Here is the crux of the South's social and economic situation today. With revenue from cotton reduced, with revenue from tobacco not likely to increase greatly, with a present ample production of other high-value-per-acre crops, what is the South to do with its surplus population?

When we turn to more machinery with which to make our production costs less we displace people. When we turn to livestock as an extra source of cash income we find more acreage must go into pasture and low value per acre feed crops, we find more of the work being done by livestock, and again we displace people. Every way we turn in an effort to save ourselves we displace people. This is a serious social and economic problem.

One cannot help but feel that the development of new industries from one end of the South to the other is one of the South's greatest needs, because in that way we might help give employment to people who are not now needed on Southern farms.

Aside from the necessity of introducing machinery to lower production costs, aside from the necessity of developing a livestock industry as a means of gaining new income, let us see what happens even if we had neither of these problems confronting us. I take you to a plateau in Alabama, known as Sand Mountain. Thrifty Anglo-

Saxon stock settled this country some three generations ago. At that time ample land was available. As families increased in size more land was cleared. As boys grew up farms had to be divided and the acreage per family became smaller. The division and re-division has now progressed to the point where it will no longer be possible to subdivide and leave families with sufficient acreage on which to provide a living. Already a tire plant has located near by. A small spinning mill has been built in one of the principal towns in this area, but still the surplus labor has not yet been provided for. Hundreds have left to go to larger cities in the South and in the North and still this area is faced with a problem of over population.

Even if world conditions improve and the prices of farm products rise to old time levels we still will be faced with the problem of providing profitable employment for unneeded farm labor. The only answer to this probably lies in the continued and more rapid expansion of industrial development in the South. More industries, large and small, widely distributed over the South are needed to give relief to the farms of the South now weighted down with this heavy burden.

The large rural population of the South imposes heavy social obligations. Think of the cost of providing schools, churches, community centers, etc., for such a large and scattered population. These problems are further complicated by the fact that people of two races are to be provided for. That means a dual system of schools and churches and community centers as well as other dual facilities. No wonder it has been so difficult to bring up the standards of our rural schools in anything like approximate keeping with those of the cities.

According to the 1935 census we have 3,367,000 farms in the South. But please bear in mind the Census Bureau's definition of a farm. Outside the South where farm labor is paid a cash wage the farm laborer is not classed as a farmer. In the South where much of our farm labor is paid in the form of a share of the crop, the laborer is classed as a farmer and all statistics are averaged in accordingly. When you have occasion to make comparison between the South and other sections we hope you will keep this in mind. If farm labor is to be averaged in one section of the country it should be so included in all sections. A 500 acre farm in another section of country is classed as one farm. A 500 acre farm in the South may be counted as 9 farms because it has one owner and 8 sharecroppers on it. One can easily see how badly figures can be thrown out of line.

Of the more than 3,300,000 farms in the South (census count) 1,700,000 are of less than 50 acres in size. Since the share cropper seldom works more than about 35 acres, it is assumed this group, less than 50 acres in size, includes most of the share croppers. This leaves, however, more than 1,600,000 farms ranging from 50 acres on up. This higher income group furnishes the solid skeleton foundation on which a strong rural buying power of the South rests.

Since we have heard so much about poverty in the South has it ever occurred to you that of all farmers in the United States receiving an annual cash income of $1,000 or above, that more than one-third of them are in the 14 states of the South? The census of 1930 showed more than one million of the farms of the South have an annual cash

income of $1,000 or more. Conservative authorities have estimated that $1,000 cash income on the farm is equivalent to about $1,600 income in the cities.

For the year July 1, 1935, to June 30, 1936, the Bureau of Home Economics, U. S. Dept. of Agriculture, made an exhaustive survey in a study of consumer purchases. A projection of this survey discloses that for that period there were in the United States nearly 3,000,000 high-income farm families with average incomes of $1,907 per year. Of these more than 1,000,000, 36.6% lived in the South. Furthermore, the average income for those of this high-income group living in the South was $2,002. This projection also shows that of all farm money spent in the United States for consumer goods 39.3% was spent by southern farmers; for automotive products 36.2%; for transportation other than by auto 43.7%; for food 39.3%; for clothing 47.1%; for household furnishing 39.6%; for recreation 39.5%; for housing 34.3%; and for personal care (toilet articles, cosmetics, etc) 40.2%

Thus you can see, as we stated in the outset, the South is a country of sharp contrasts. Our great problem is population and how to give it gainful employment while readjusting the management of our farms away from the extravagant use of hand labor, trying to strike somewhere that happy balance that will give a comfortable living for all and enable every family to enjoy a fair share of the better things of life.

AGRONOMIC PROBLEMS OF THE SOUTH[1]

M. J. FUNCHESS[2]

NEARLY a year ago your President caught me in an unguarded moment and induced me to consent to prepare a paper for this meeting dealing with the subject, "Agronomic Problems of the South". Before attempting to enumerate and enlarge upon some of the specific problems that the agronomists should tackle in their efforts to improve southern agriculture, let me give you a few comparative figures which picture agricultural conditions in the South. The comparative figures deal with ten southern states that produce a large amount of cotton, and a specific comparison between Alabama and Iowa. The average cash returns from all crops per capita from ten southern states in 1937 amounted to $104. For Alabama, this figure was $73 and for Iowa $77. The cash returns from all livestock and livestock products from the ten southern states was $45, from Alabama $20, and from Iowa $469. Cash returns from all crops, from all livestock, and from Government payments for the ten states was $158, for Alabama $100, and for Iowa $571. These very great differences in per capita income may be readily understood from the following figures. The number of acres of farm land per capita in the ten states was 24, while in Alabama it was 14, and in Iowa it was 35. The number of acres of harvested crops for the ten cotton-producing states was 7, for Alabama it was 5, while for Iowa it was 20. In 1937, Alabama farmers planted 3,493,000 acres of corn that produced an average of 14 bushels per acre, or a total of approximately 49,000,000 bushels of corn. That same year, Iowa farmers planted 9,636,000 acres of corn with an average yield of 45 bushels per acre and a total production of 438,438,000 bushels. The Iowa farmer planted nearly three times as many acres of corn, but produced nearly ten times as many bushels as the Alabama farmer secured for his effort. Alabama farmers had 132,000 acres in oats that produced an average of 24 bushels per acre and a total crop of 3,168,000 bushels. The Iowa farmers planted nearly 6,000,000 acres in oats; produced an average of 33 bushels an acre, and harvested 198,000,000 bushels of oats. These figures relative to acreages and yields readily explain why the average farmer in ten southern states secured a total cash income of $158, and why the Alabama farmer secured a cash income of only $100, while the Iowa farmer secured an average of $571 per capita. It is perfectly clear that southern farmers will not be much better off than at the present time until their production of farm crops is increased. The southern farmer can never produce much in the way of livestock or livestock products until there is an adequate production of feed and forage. These opening statements clearly indicate in a general way the nature of the most important problems that the southern agronomists must tackle.

In the following pages, an attempt is made to present to this group a discussion of some of the unsolved or partially solved agronomic

[1]Presented on the general program of the thirty-second annual meeting of the Society held in New Orleans, La., November 23, 1939.

[2]Director, Alabama Agricultural Experiment Station, Auburn, Ala.

problems of the South. It is not claimed that this is a complete list of problems falling in these categories. Probably the list might be very greatly extended. In presenting this list of suggestions, the views expressed are those of the writer and of the staff of the Agronomy Department of the Alabama Experiment Station. No attempt has been made to make a composite list of problems based on suggestions from other southern experiment station groups.

A glance at reported crop yields from most of the southern experiment stations will show that yields from check plots and from plots receiving good fertilizers are sometimes double or even treble the average crop yields from the particular state in which the report originates. This means that in practically all cases field plot experiments are located on land that is very much more productive than the average land in the area represented. The question might well be raised as to whether or not results from this good land may safely be considered to apply to average land or lands that are poorer than the average. In Alabama, evidence is accumulating which sharply warns us against drawing sweeping conclusions for all kinds of soil, based on experiments conducted on a few kinds of soil. A few examples may be given to illustrate this point. Based on a number of cooperative experiments, our Agronomy Department concluded that mineral fertilizers were rarely needed for corn when it was planted in rotation with other crops which were fertilized. Experiments on our substations supported this opinion. Nevertheless, when the Experiment Station bought some very poor, rolling, sandy land and began to farm it, there was found a need for potash so great that corn almost failed without potash applications. In the Piedmont section of Alabama, erosion has been severe leaving only a thin surface soil. Accumulating evidence strongly indicates that on such land farmers receive very much smaller increases from given applications of fertilizer than are received from land not severely damaged by erosion. These kinds of observations are causing some of us to question pointedly how far it is safe to make recommendations for widely varying soil conditions when the recommendations are based on trials conducted on land far above average productivity. These kinds of results should make the cautious investigator question whether or not he can safely recommend the kind and amount of fertilizer that is most economical for a large number of soils and soil conditions that are not represented in his field experiments. In the lower South, peanuts occupy an ever increasing acreage. A large part of the crop is harvested and sold. Farmers know that harvesting peanuts is hard on the land. What kind of fertilizer should be applied to a crop that follows harvested peanuts? Preliminary and unpublished evidence indicates that the agronomist is unprepared to give a real good fertilizer recommendation for such crops.

The usual fertilizer sold today is considered to be valuable chiefly because of the NPK elements contained. How long will this assumption stand? Without attempting to answer this particular question, it may be pointed out that when land is overlimed it may immediately develop a need for elements in addition to NPK. For certain crops, the evidence indicates that there are many sandy lands in the South

that contain very small amounts of the so-called rare elements. The work of Doctor Sommer at the Alabama Station indicates definitely that the use of pure salts in a cropping system soon develops a condition where NPK alone is quite insufficient for crop production. Under greenhouse conditions, the need for some kind of so-called rare elements is developed after a few years intensive cropping in pots. The continued use of low grade fertilizer may incidentally supply most, or all, of these rare elements. On the other hand, the laws of economics and the production of synthetic materials are driving us toward the use of more concentrated fertilizers. Doctor Tidmore of the Alabama Station has shown a possible saving of $115,000 annually in Alabama if the grade of superphosphate now in use be increased from 16 to 18 per cent of phosphoric acid. Additional savings that might be made through the use of higher grades of other materials and of mixed fertilizers should make a total much greater than that which is possible from the use of higher grades of superphosphate. If concentrated fertilizer becomes more general, the agronomists should be prepared to state whether rare elements are needed and the amount that should be applied to make up the deficiencies in the various soil types. If and when the time comes when rare elements must be applied, the agronomists may be called on to advise the manner of application or the method of incorporating uniformly small amounts of material in the usual fertilizer so as to supply economically the rare elements in question. It may not be considered strictly an agronomic problem, but the agronomists will be involved in finding an answer to the question that is sure to be raised as to the food and feed value of crops grown on land that is deficient in some of the rare elements. This rather extended discussion of the possible needs of rare elements in fertilizer should not mislead anyone to conclude that there may be an urgent need for their application in fertilizer now. This discussion is intended to bring out the possibility of the need for both extensive and intensive work in the future to answer questions along this line, which questions might be quite important when they develop.

Soil erosion and the ill effects of soil erosion are topics of discussion by a horde of agricultural workers. Funds available for study and control of soil erosion amount to a sum greater than that available for any other subject studied by experiment stations and the Department of Agriculture. Nevertheless, it is probably true that we know less about soil erosion and methods of control than we do about many other agricultural problems. It is generally assumed that organic matter plays an important part in the control of soil erosion, but one would probably get a vague answer if one requested definite proof. Who knows the function or the functions of soil organic matter? Who knows the possible importance of the part organic matter plays in stimulating biological activities in soil? To push this thought further, one might ask who knows the importance of biological activities? Is it not probable that we have been putting a disproportionate amount of emphasis on soil chemistry and more or less slurred over the possible importance of soil physics and soil biology? Many of us possibly have seen great volumes of water flowing over bare soil

without any evident erosion. In such cases, apparently the soil was held against erosion by some kind of organic growth. This is an observation and not a statement of fact. If it is found to be true, what part does active soil organic matter play under such conditions? Is soil organic matter important because it holds much water, or is it important because it helps conserve soil water? Or is it important because of its binding power, or its value as food for soil organisms? Why are gall spots proverbially poor? Gall spots contain little or no organic matter. Soil in such spots may contain just as much mineral nutrients as in uneroded areas. Nevertheless, even with commercial nitrogen added, gall spots usually produce little or no crops. Usually the gall spots are the only ones on which a stand of crop fails. Does the gall spot suffer more from drouth than uneroded land? Someone may try to answer these questions, but if convincing evidence is asked for to back up the answer, it is extremely doubtful if such evidence would be forthcoming. This leads to a question as to the possible value of barnyard manure. Is it valuable only for its NPK content? Even though this question may have been answered in the affirmative by someone, there are many who do not accept such an answer. When manure is applied to a gall spot, the results are striking. However, the equivalent amount of commercial fertilizer may fail almost completely to produce a crop. Applications of manure have controlled root-rot of cotton while commercial fertilizers had no effect on it. What is the value of organic matter in making mineral nutrients available? Much work has been done along this line, but we do not have an answer that explains fully the results. For example, Scarseth, formerly of the Alabama Experiment Station, accurately determined that available phosphates when applied to bare soil in pots in the greenhouse became quite unavailable in one season. However, on the same soil in the field, a heavy application of phosphate has continued to give a splendid response four years after the application was discontinued. There is no definite explanation for the difference between the results obtained in the field and those obtained on bare soil in pots in the greenhouse. May we assume that this difference is due to the action of soil organic matter and plant roots and plant residues? This discussion leads to still another question. If the changing agricultural conditions bring about an increase in grazing crops and more winter cover crops in the South, will there not need to be developed through experimentation another set of fertilizer recommendations for these changed conditions? If more crops are grazed on the land, might there not be a reduced need for mineral fertilizers and nitrogen? Might there not be needed a different ratio under such conditions from that needed under the present conditions where row crops largely prevail?

With the exception of certain small areas, practically all cultivated lands in the South are acid to some degree. However, liming is not generally practiced. This is due in part to the fact that the system of farming usually followed does not include crops that respond well to lime. There are indications that the farm program on thousands of southern farms will be materially changed in the next few years. The change that is most likely will be to a system that would include

crops which frequently respond to lime. There is an urgent need, therefore, for a "quick test" that would determine where lime would pay. Note especially that emphasis is put on whether or not lime will pay. There may be a number of methods that will determine whether or not a sample of soil is acid to some degree. However, it is extremely doubtful if there are methods available now that answer the all-important question of the farmer, "Will it pay me to lime this particular field?" An example may illustrate this point. A number of years ago the Alabama Station established an experiment field in the Piedmont area. Chemical tests indicated the soil to be very slightly acid. Nevertheless, an application of lime nearly doubled the yield of cowpeas the first year. When it was understood that cowpeas are supposed to be an acid tolerant crop, the complete failure of the chemical method in this case is evident.

As the type of farming changes in the South, important liming questions should be answered, such as, how much lime will be needed on a given soil under a given system of farming? Should small amounts be applied annually, or may large amounts be applied at infrequent intervals? Are small particles of lime actually washed into the subsoil when sandy soils are limed? On what soils may a reasonably pure calcium lime be applied and where should a dolomitic lime be used? How much lime will different soils stand before overliming injury is obtained? All of these are practical questions that should be tackled now so that answers will be available when a changed type of farming in the South calls for such answers.

This leads to a brief discussion of quick tests in general. Earlier in this paper it was indicated that there was a great need for information relative to the fertilizer needs of soils under a vast number of conditions not represented by the usual field test. The soil chemists may render an extremely valuable service through the development of really reliable quick test methods to determine fertilizer needs on various soils and for various crops not now represented by field tests. Reliability of such tests must be beyond reasonable doubt. Farmers now use from twelve to twenty million dollars worth of fertilizer in each of several southern states. Fertilizer practice that involves such huge sums of money must be on as firm basis as possible. Farmers should not be the victims of poor judgment and bad advice based on faulty methods.

While we are still talking about fertilizers and soil amendments in general, it might be profitable to discuss briefly several questions relative to the leaching of fertilizers. It appears to be generally assumed that certain nitrogenous fertilizers are quite readily leached from soils and that most nitrogenous fertilizers may be leached fairly easily. Accumulating evidence indicates that on certain soils the danger of leaching is almost nil even if nitrates are used. On the other hand, on sandy soils and in humid climates, nitrogen losses from leaching may be severe. There is some evidence that indicates considerable loss of mineral elements by this means also. But there is no great amount of available information relative to losses of nitrogen by leaching, under field conditions. In connection with the mineral elements, there are but few carefully conducted, convincing experiments to show the

extent of leaching losses. In most cases, southern farmers apply more phosphoric acid than is removed in the crop. In the case of truck farming, many times more mineral elements are applied than are removed in the crop. Is there a single agronomy department in the South that can present a clear-cut picture of the final disposition of applied mineral fertilizer elements? How much of such material is lost by erosion? How much of it is lost by filtration into the subsoil? How much of these losses, if any, may be prevented by different and better cropping systems? When it is recalled that millions of dollars are spent annually for fertilizers in the South, it immediately becomes apparent that these types of questions are pertinent.

If the question be asked, what is the object of land preparation?—both the soils men and the agricultural engineers would probably feel that it is their job to answer this question. The chances are good that neither has a good answer. Is the same type of preparation needed on sandy soils as that which may be necessary on the clay loams and clays? Who knows what soil structure is best for biological activities and the production of plants under a given set of conditions? Why do some soils erode much more rapidly than others even though the slope and cover may be identical? Is this difference in erodibility due to structure alone, or is it due to a difference in organic content, or both? If due to a peculiar soil structure, could such a structure be changed by practical means? What are the objects of cultivation? What is accomplished by the cultivation of a crop beyond weed control? May we not devise methods of planting and cultivation that will reduce the labor charge against some southern crops which now have a high labor requirement? All of these are subjects worthy of the best effort of the agronomists, and if need be, the agricultural engineer, cooperating. Possibly it may be turned around and the burden of responsibility placed jointly on these two groups of people, since neither one alone has the training, the background, and experience to handle these types of projects satisfactorily.

A large percentage of the farms in the cotton belt of the South are without improved pastures. Real pasture land occupies a very small percentage of the land in farms. In recent years, there has been a steady increase in the interest in livestock and in pasture production. Unfortunately, the agronomists have done but little in the interest of pasture development. To be sure, there are a few pasture experiments, but there is only limited information relative to the subject that is known to be applicable over a wide range of soil conditions. In the main, the pasture problem in the South hinges around the maintenance of nitrogen. The chief pasture problem, therefore, will deal with legumes suitable for pastures under southern conditions. Many southern soils are so poor that they will probably produce pasture plants with such a low mineral content that animals will suffer from mineral deficiencies when grazed on these lands. The agronomists should determine the limit of these areas and find the necessary correctives for such lands if direct mineral feeding does not solve the problem. The limited work that has been done on pastures has already developed some real research problems. May there be a combination of legumes that will last through both summer and

winter? Such a combination would make an ideal hog pasture. What combination of legumes and grass will make the best pasture? Can there be found a summer growing legume with a winter grass, or may this be reversed to have a winter legume and a summer grass? Regardless of the angle from which the problem is attacked, the main questions to be solved relate to the production of the legume. Then, there is the question of certain smothering crops like hop clover. These may appear to be very desirable, but when the severe smothering effect of such a crop is observed, one might be lead to question whether hop clover is desirable in a pasture. At the present time, white clover appears to be the best legume for pasture production. On what soils will it grow well? What treatments are necessary on soils where it does not naturally do well? On what soils will it need lime? What strain of white clover is best? Can good pastures be made on common southern uplands? If so, what plants will be used? Will it be better to try to produce temporary pasture plants on uplands than to try to depend on permanent pastures? Is drouth more severe in its effects on permanent pasture or temporary pastures on uplands? At the present time, permanent pastures are much more prominent than temporary pastures. The effect of severe drouth on permanent pastures is well-known, and when livestock farmers have their pastures so badly burned by drouth that they must resort to buying feed to tide them over the distress period, they well remember it. How far may temporary grazing crops be supplied to carry livestock through such drouth periods when the permanent pastures are burned out? Experiments in management on the Black Belt Station in Alabama indicate that this is one of the most important fields of experimentation. All these kinds of pasture problems must be tackled by the agronomists if a foundation is to be laid on which the animal husbandmen may build a reasonably profitable livestock production program in the South.

In all probability, the greatest opportunity for service by the agronomists of the South lies in the field of plant breeding. Aside from a great deal of breeding work done on cotton, plant breeding operations by the several experiment stations have been rather limited in scope until the last few years. Recently, a few of the southern stations have started rather extensive plant breeding programs; however, the field has scarcely been touched. Some of the needs that might be met through the operations of the skilled and well-trained plant breeder are listed in the following paragraphs.

In the southeastern states, vetch, Austrian peas, and crimson clover are common winter cover crops. These are now planted to the extent of some 45 or 50 million pounds of seed annually in the three states of Georgia, Alabama, and Mississippi. Vetch and Austrian peas are both subject to a number of destructive diseases. If disease resistant strains of either of these, or both of these, were available, the winter cover crop program could be put forward more rapidly than it is moving at this time. Neither vetch nor Austrian peas is a good seed producer. Many millions of pounds of seed are bought annually. The necessity of buying seed and the scarcity of cash with which to buy seed are factors that operate seriously against the expansion of

the use of these two crops for soil cover and improvement. If there were available in the South a strain of vetch or Austrian peas that was highly resistant to disease and produced seed freely, the winter cover crop program in the South could be made very much more effective and extensive than it is. Crimson clover is fairly well adapted to much of the southeastern states. It would be a much more valuable crop if it had a considerable percentage of hard seed, which would enable the grower to use it without the necessity of reseeding each year. A crimson clover strain that matured earlier than the common variety would be highly desirable.

Common lespedeza is found on a wide range of soils throughout the entire southern states. Among its weaknesses are its slow growth in early spring and its small root system. It might be a more serviceable crop if it had more hard seed. If some plant breeder will produce a much more vigorous strain of common lespedeza, and especially a strain with more vigorous root system, the possible value of such an improved strain would be difficult to forecast. Lespedeza sericea is a crop of considerable promise, but as long as farmers must grow a strain with a high tannin content, the crop will not be as valuable as it could be. The plant has a tendency to shatter its leaves very easily. It is also a little coarse. Why can't some energetic plant breeder develop a strain of Lespedeza sericea that has fine stems, that holds it leaves well, and that has a low tannin content?

Among the grasses, Dallis and Bermuda are the most common in pastures in the South. At the Georgia Coastal Plains Station, breeding work is under way to secure an ergot-free strain of Dallis grass and an improved strain of Bermuda grass. Even a casual inspection of the work under way at that Station indicates the almost unlimited possibilities for improvement in these two varieties of pasture grasses. The quality of bluegrass as a pasture plant is well-known throughout the livestock producing areas above the Cotton Belt. The crop does not do well in the greater part of this area. Is it too much to hope that the plant breeder could secure a strain that could be grown much further south than bluegrass is now supposed to be adapted? If bluegrass could be added to the other pasture grasses, more rapid improvement in pasture in the Cotton Belt could be effected. In the light of existing information, white clover is the most promising legume for pasture development in the South. The crop will stand severe cold and is adapted to a considerable range of soil and climatic conditions. Plant breeders interested in pasture development should find in white clover a crop that challenged the best that is in them. By the latter part of May, due to heat or drouth or to both of these, white clover usually disappears from pastures. This is particularly true on upland. In moist positions, white clover may persist through a good part of the summer. This leads to speculation as to the possibility of discovering strains sufficiently resistant to drouth and hot weather to enable them to grow throughout most of the summer months. The crop does best on lands that are only slightly acid. May not acid-tolerant strains be found? An acid-tolerant strain of white clover might extend its use over countless thousands acres of land that would need to be limed for the usual strains of white clover.

There are already several existing strains of this plant, but it is quite probable that the possibility of improvement through selection and hybridization has scarcely been touched. Since the maintenance of nitrogen is fundamental in the maintenance of southern pastures and since white clover has a growing season that fits in well with the present pasture program of a legume and a grass, the potential value of this crop in southern pastures can scarcely be over-estimated.

Peanuts now occupy a large acreage in the southeastern states, and the importance of the crop is increasing. But little work has been done on peanut improvement except at one or two experiment stations. The possibility of increasing the yield through plant selection and hybridization has scarcely been touched. Most kinds of peanuts are subject to a number of diseases. Few of these diseases can be economically controlled by application of chemicals. Might not the plant breeder provide disease-resistant strains of peanuts just as we now have wilt-resistant cotton, rust-resistant wheat, etc? Some varieties of peanuts produce a high percentage of "pops". Is it too much to expect that some plant breeder might take an otherwise desirable variety of peanut and increase the production by breeding for freedom from "pops"? Some of the best varieties of peanuts have too long a growing season to fit into a farm program near the upper limits of the Cotton Belt. The so-called Alabama or North Carolina runner is in this class. If some plant breeder could produce a high-yielding strain of this type of peanut that would mature three or four weeks earlier than the strains now being used, the area suitable for producing peanut-fed hogs could be greatly extended. In certain sections, soybeans are being grown chiefly for their oil content. Is it not possible to produce a high-yielding strain of peanuts with a high oil content that would enable southern farmers to grow peanuts for the oil content just as some Corn Belt farmers are now growing soybeans for oil? A considerable part of the southern peanut crop is harvested. Where runner peanuts are harvested, farmers lose from 15 to 20 per cent by having them stripped off in the soil when the plants are plowed up. To be sure, these shattered peanuts may be salvaged by hogs. There are thousands of tenants who do not have hogs with which to salvage these peanuts. A non-shattering strain would increase the value of harvested peanuts under these conditions to the extent of possibly covering the cost of production.

The so-called rust-resistant varieties of oats, like Texas Rust Proof, have but little rust resistance when planted near the Gulf Coast. Frequently, farmers in areas within 100 miles of the Gulf Coast lose their oats entirely because of rust damage. The production of a high-yielding strain of oats that would be resistant to rust under these conditions would be a very valuable addition to the crops available for use on thousands of farms. Oats are frequently subject to lodging under the weather conditions existing in the South. A strain with a straw sufficiently stiff to stand up under southern thunderstorms would be highly valuable.

There might be listed a number of problems in connection with breeding corn for the southern states. One of the most important is the production of a high-yielding variety with shuck covering that is

long and tight enough to protect the ear from the ravages of weevils and ear worms. Superior yielding strains or hybrids cannot make much of a showing on land that produces, say, 15 bushels per acre. Where high yields are possible, there is great need for better yielding kinds of corn.

The most important cotton breeding problems involves improvement of quality, yield, and disease resistance. It has taken the cotton breeder many years to combine high yield with good quality. However, much progress has been made along this line in recent years. Yet, there remains much to be done. This is particularly true in areas where cotton wilt is severe. There is room for much improvement in the quality of the wilt-resistant strains and varieties now available. The plant breeders are still struggling with breeding methods in connection with wilt resistance. Apparently, there may be a number of strains of wilt. If there are not a number of strains of wilt, then it appears that a given strain may act differently in different soils and at different fertility levels. The plant breeder has found more or less difficulty in uniformly inoculating soils with wilt organisms. How far do the different fertility levels influence susceptibility to wilt? How far do adequate amounts of the common plant nutrients, particularly potash, affect susceptibility to wilt? To what extent might strains of cotton be developed that are resistant to the seedling diseases that frequently injure the stands of cotton? There appears to be almost unlimited opportunities for the improvement of cotton along the general lines indicated by these suggestions and questions.

The agronomists may not realize it, but on their shoulders may rest the responsibility for building an improved farm program for the South. It is not enough for the specialists to turn out isolated pieces or research and leave the application of such results to someone else. When research findings are given to the public, the researcher who is most valuable is the one who can see clearly where his results will apply and goes about teaching the public where and how they may be applied. However, the agronomist should avoid becoming a "promotionist". It is unfortunate when we feel that it is up to us to "push our line". As specialist in agronomy, the best service is rendered when the worker is familiar enough with the farm problem to help work his findings into the farm program where he serves. If he does not, who will?

As a final topic, let me discuss briefly a subject that is not agronomic, but that is of interest to all agronomists in particular and to all agricultural workers in general. It is necessary to scan only a few advertisements to find cases where either an individual, a firm, or a corporation is advertising some kind of seed or some kind of fertilizer in a way that is misleading to the prospective purchaser. In these instances the fertilizer and seed advertisements completely ignore recommendations of experiment stations. Through extensive advertising the attempt is made to induce farmers to use fertilizers and materials that are unsatisfactory both as to the ratio of the elements and the amounts applied. Seed advertisers make extravagant and unsupportable claims as to the yield and the quality of the crop that can be made by planting the particular variety that they have to sell.

After large amounts of public funds have been spent in the interest of agronomic experiments to determine the best variety of a given crop or the best fertilizer practice for farmers in an area or in a state, the agronomists in particular and all agricultural workers in general should feel a responsibility to counteract the effect of false and misleading advertising by those who may have seed or fertilizer for sale which do not fit in with the program for a given area or state. Fortunately, the amount of such bad advertising is small. Nevertheless, it should be our responsibility to try to protect farmers against those people who apparently have little or no interest in the welfare of the consumer, but appear rather to take the attitude that let the buyer beware.

This incomplete list of agronomic problems indicates that the agronomists who serve best in the South in the future will put much less emphasis on cotton than they have in the past and will put increasing effort into the development of a feed, forage, and pasture program on which may be based an increased production of livestock with which to balance the South's cotton crop.

A GENETIC STUDY OF MATURE PLANT RESISTANCE IN SPRING WHEAT TO BLACK STEM RUST, *PUCCINIA GRAMINIS TRITICI*, AND REACTION TO BLACK CHAFF, *BACTERIUM TRANSLUCENS*, VAR. *UNDULOSUM*[1]

C. L. PAN[2]

DURING the last 20 years, numerous attempts have been made to breed hard red spring wheats that are resistant to stem rust and otherwise desirable. The present investigation was made to study the genetic nature of stem rust reaction under field conditions to many physiological races, using for these studies crosses between several rust-resistant spring wheats. Opportunity presented itself to study the nature of inheritance of resistance to black chaff.

MATERIALS AND METHODS

A brief description of the parental material will be of interest. Marquis×H44, III-31-7, was obtained from the Dominion Rust Research Laboratory, Winnipeg, Canada. It is resistant to stem rust but susceptible to black chaff. Pentad×Marquis, III-34-1, also obtained from the Dominion Rust Laboratory, is semi-resistant to stem rust and resistant to black chaff. Double Cross, II-21-80, from the Minnesota Experiment Station, was obtained from the cross (Marquis×Iumillo)×(Marquis×Kanred). It combines moderate resistance from the Iumillo durum parent in the mature plant stage under field conditions to many physiological races of stem rust with immunity to the stem rust races to which Kanred is immune in the seedling stage. Hope and H44, obtained by McFadden from a cross of Yaroslav emmer×Marquis, are resistant under field conditions to both stem and leaf rust.

F_2 plants of the cross III-31-7×III-34-1 were grown in the greenhouse during the winter of 1933-34 and the parents, F_1, F_2, and F_3 generations were grown in the rust nursery either in 1934 or 1935 or in both years under an epidemic induced by using rust races available and prevalent in the spring wheat area.

New crosses were made between Marquis×Hope, III-31-7, with Hope and H44, and the parents and F_1 generation grown in 1934 and 1935 under stem rust epidemic conditions while the F_2 backcrosses were grown in 1935.

Crosses were also made between Pentad×Marquis, III-34-1, with Double Cross, II-21-80, H44, and Hope. The parents, F_1, F_2, and backcrosses were grown either in 1934 or 1935 or in both years in the rust nursery.

An epidemic of stem rust was produced artificially while black chaff developed naturally. Plants were classified for reaction to stem rust and to black chaff.

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[2]Senior plant breeder and acting head of the Department of Rice of the National Agricultural Research Bureau of China. The writer wishes to express his appreciation to Dr. H. K. Hayes, Professor and Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, for his valuable advice in methods of conducting this experiment and in the preparation of this manuscript.

EXPERIMENTAL RESULTS

REACTION TO STEM RUST

Marquis×H44, III-31-7×Minn. Double Cross, II-21-80.—The data given in Table 1 show that most of the parental plants or rows of Marquis×H44, III-31-7, were resistant to stem rust while Minn. Double Cross, II-21-80, was mostly classified as semi-resistant. Considerable variation in rust reaction was found within each of the parents, which may be due partly to mechanical mixture or natural crossing. Such variation had also been found by Hayes, *et al.* (4)[3] and by Ausemus (1).

There were 357 F_2 plants grown in the field in 1934, 185 being classified as resistant, 102 semi-resistant, and 70 as susceptible. The F_2 plants grown in 1935 were classified as 230 resistant, 137 semi-resistant, and 74 susceptible.

From backcrosses of F_1 of II-31-7×II-21-80 to the resistant parent Marquis×H44, III-31-7, 82 resistant, 20 semi-resistant, and 6 susceptible plants were obtained. The six susceptible plants were rather unexpected. One of the parental plants of Marquis×H44, III-31-7, used for the backcross probably was genotypically susceptible since one such plant was obtained from that parent grown in 1934.

The plants obtained from the backcross of F_1 to the semi-resistant parent, Minn. Double Cross, II-21-80, were classified as 28 resistant and 31 semi-resistant, being very close to a ratio of 1:1.

Of the F_3 lines grown in 1934, 9 bred true for resistance, 5 bred true for semi-resistance, 24 bred true for susceptibility, 28 segregated for resistance and semi-resistance, 20 segregated for resistance and susceptibility, 49 segregated for resistance, semi-resistance, and susceptibility, and 9 segregated for semi-resistance and susceptibility.

The results so far discussed may be explained by assuming that Minn. Double Cross, II-21-80, has two complementary factors for semi-resistance, i.e., in the presence of these two genes semi-resistance is produced and Marquis×H44, III-31-7, carries a single dominant gene for resistance. Accordingly, the F_1 plants would be resistant and in F_2 a ratio of 48 resistant, 9 semi-resistant, and 7 susceptible would be expected. The F_2 results obtained in the 2 years did not agree well with the expected ratio on account of too few resistant plants. However, the proportion of semi-resistant and susceptible plants indicated a good agreement with a ratio of 9:7. The F_3 progenies from a random selection of F_2 plants agreed fairly well with the hypothesis. The data from the backcross, in general, could be explained by the hypothesis. The F_4 reactions also were in fair agreement with the hypothesis suggested. It seems probable that the results of the present study can be explained logically by the proposed hypothesis which was made on the basis of facts actually found by many previous workers. Close agreement between theory and results can not be expected when the parental reactions show as wide fluctuations as in the present study.

[3]Numbers in parenthesis refer to "Literature Cited", p. 115.

TABLE 1.—*Mature plant reaction to stem rust under field conditions of parent, F_1, F_2, and backcrossed plants, and in parent rows and F_3 and F_4 lines grown in 1934 and 1935.*

Parents and generations	Plant, lines or rows	Years	Parental reaction	No. of plants, rows or lines showing indicated reaction*							Total
				R	SR	S	R–	H–	H	S–	
Marquis×H44, III–31–7	Plants	1934		752	40	1	—	—	—	—	793
Marquis×H44, III–31–7	Plants	1935		80	2	—	—	—	—	—	82
Minn. Double Cross, II–21–80	Plants	1934		32	736	24	—	—	—	—	792
Minn. Double Cross, II–21–80	Plants	1935		1	73	—	—	—	—	—	74
III–31–7×II–21–80, F_1	Plants	1934		11	—	—	—	—	—	—	11
III–31–7×II–21–80, F_2	Plants	1934		185	102	70	—	—	—	—	357
III–31–7×II–21–80, F_2	Plants	1935		230	137	74	—	—	—	—	441
Marquis×H44, III–31–7×F_1	Plants	1935		82	20	6	—	—	—	—	108
Minn. Double Cross, II–21–80×F_1	Plants	1935		28	31	0	—	—	—	—	59
Marquis×H44, III–31–7	Rows	1934		34	—	—	9	—	—	—	43
Marquis×H44, III–31–7	Rows	1935		10	—	—	—	—	—	—	10
Minn. Double Cross, II–21–80	Rows	1934		—	30	—	6	—	—	9	45
Minn. Double Cross, II–21–80	Rows	1935		—	9	—	1	1	—	—	11
III–31–7×II–21–80, F_3	Lines	1934	Random	9	5	24	28	20	49	9	144
III–31–7×II–21–80, F_4	Lines	1935	R	52	0	0	17	0	12	0	81
III–31–7×II–21–80, F_4	Lines	1935	SR	1	5	—	2	2	4	0	14

*R = resistant; SR = semi-resistant; S = susceptible; R– = lines or rows segregating for R and SR; H– = segregating for R and S; H = segregating for R, SR and S; and S– = segregating for SR and S.

Marquis×H44, III–31–7,×Hope and H44.—The F_1, F_2, and backcrosses were studied to determine whether the same factor or factors was responsible for stem rust reaction. All plants grown were classified as resistant except 4 out of a total of 196 plants of III–31–7 that were classified as semi-resistant. The data clearly show that no segregation existed in these two crosses, indicating that the genetical factor or factors governing the rust resistance of the parent Marquis ×H44, III–31–7, is or are allelomorphic to the factor or factors for resistance in Hope and H44.

Pentad×Marquis, III–34–1×Minn. D. C. II–21–80 and Pentad ×Marquis, III–31–1×Hope and H44.—The great preponderance of semi-resistant plants in F_1 and F_2 and in the backcrosses for Pentad ×Marquis, III–34–1×Minn. Double Cross, II–21–80, showed that the two complementary factors for semi-resistance in Minn. Double Cross, II–21–80, are also present in Pentad×Marquis, III–34–1, although modifying factors of minor importance may be present (Table 2).

It should be noted that five plants of the parent, Pentad×Marquis, III–34–1, out of 69 were classified as susceptible. It seems probable that these variations are due to fluctuations and accordingly a certain proportion of similar plants should be obtained in F_2 and in backcrosses to III–34–1. The results of the crosses between III–34–1 with Hope and H44 agree fairly well with the hypothesis that two complementary factors are responsible for the rust reaction of Pentad× Marquis, III–34–1 and that these factors are not closely linked with the factor or factors responsible for stem rust reaction of Hope and H44.

The experimental results presented have suggested an hypothesis which explains the results fairly well for all crosses studied and also is in agreement with conclusions reached by previous workers. The parental variety, Marquis×H44, III–31–7, proved to be resistant to stem rust in the mature plant stage in the field. The resistant factor in this variety was of course obtained from the parent, H44. According to Hayes, *et al.* (4) and to Neatby and Goulden (5), H44 carries a single genetical factor for resistance; consequently, the parent Marquis×H44, III–31–7 must also have that gene governing its resistance. When this parent was crossed to H44 and Hope, all hybrid plants were resistant, there being no segregation. Indirectly, a genetic factor for resistance in the Hope parent proved to be allelomorphic to the one for the H44 type of resistance. This conclusion is logical because Hope and H44 were sister selections from the cross Yaroslav emmer×Marquis. However, according to Neatby and Goulden (5), Hope has an entirely different genotype for rust resistance, although it is a sister selection of H44–24. The results given here do not support their conclusion.

Hayes, Stakman, and Aamodt (3) found that the Marquillo type of resistance was governed by the interaction of two complementary factors when it was crossed with Marquis×Kanred. Neatby and Goulden (5) also found that Minnesota Double Cross carries two complementary factors for semi-resistance. The data obtained from

TABLE 2.—*Reaction to stem rust in F_1, F_2, and backcrossed plants.*

Crosses and generations	Year	No. of plants showing indicated reaction			
		R	SR	S	Total
Pentad × Marquis, III–34–1	1934 and 1935	6	58	5	69
Minn. Double Cross, II–21–80	1934 and 1935	1	78	—	79
Hope	1934 and 1935	110	—	—	110
H44	1934 and 1935	82	—	—	82
Pentad × Marquis, III–34–1 × Minn. Double Cross II–21–80 F_1	1934	1	13	—	14
Pentad × Marquis, III–34–1 × Minn. Double Cross II–21–80 F_2	1935	68	429	25	522
Pentad × Marquis, III–34–1 × F_1	1935	2	23	2	27
Minn. Double Cross II–21–80 × F_1	1935	5	32	1	38
Pentad × Marquis, III–34–1 × Hope, F_1	1934	5	—	—	5
Pentad × Marquis, III–34–1 × Hope, F_2	1935	199	72	10	281
Pentad × Marquis, III–34–1 × F_1	1935	31	40	7	78
Hope × F_1	1935	54	1	—	55
Pentad × Marquis, III–34–1 × H44, F_1	1934	11	—	—	11
Pentad × Marquis, III–34–1 × H44, F_2	1935	403	143	11	557
Pentad × Marquis, III–34–1 × F_1	1935	27	28	3	58
H44 × F_1	1935	70	—	—	70

TABLE 3.—*Reaction to black chaff under field conditions of parent, F_1, F_2, and backcrossed plants, and in parent rows and F_3 and F_4 lines grown in 1934 and 1935.*

Parents and generations	Plants, lines or rows	Year	Parental reaction	No. of plants, rows or lines showing indicated reaction			
				T*	TM	M	Total
Marquis×H-44, III-31-7	Plants	1934		268	—	525	793
Marquis×H-44, III-31-7	Plants	1935		6	—	76	82
Minn. Double Cross, II-21-80	Plants	1934		788	—	4	792
Minn. Double Cross, II-21-80	Plants	1935		73	—	1	74
II-31-7×II-21-80, F_1	Plants	1934		—	—	11	11
II-31-7×II-21-80, F_2	Plants	1934		230	—	127	357
II-31-7×II-21-80, F_2	Plants	1935		219	—	222	441
Marquis×H-44, III-31-7×F_1	Plants	1935		14	—	94	108
Minn. Double Cross, II-21-80×F_1	Plants	1935		34	—	25	59
Marquis×H-44, III-31-7	Rows	1934		1	42	—	43
Marquis×H-44, III-31-7	Rows	1935		—	1	9	10
Minn. Double Cross, II-21-80	Rows	1934		45	—	—	45
Minn. Double Cross, II-21-80	Rows	1935		8	—	3	11
III-31-7×II-21-80, F_3	Lines	1934	Random	53	81	10	144
III-31-7×II-21-80, F_4	Lines	1935	T	7	48	7	62
III-31-7×II-21-80, F_4	Lines	1935	M	2	18	13	33

*T = trace, M = medium, TM = both trace and medium reaction

the cross Marquis×H44, III–31–7,×Minn. Double Cross II–21–80, agree in general with the previous conclusion.

The genetical basis for rust reaction of the parental variety, Pentad×Marquis, III–34–1, has not been reported previously. This wheat proved to be semi-resistant to stem rust in the mature plant stage in the field. One of its parents, Pentad, is a 14-chromosome durum wheat. Minn. Double Cross, II–21–80, was a sister selection of Thatcher obtained from the cross, (Marquis×Iumillo)×(Marquis ×Kanred), Iumillo belonging to the same species as Pentad. With this similarity of origin, it is logical that the parent, Pentad× Marquis, III–34–1, may have the same general genetical constitution for rust reaction as Minn. Double Cross, II–21–80, although there is some evidence of minor differences which may result from minor modifying factors. When these two parents were crossed, most of the hybrid plants were semi-resistant.

REACTION TO BLACK CHAFF

An epidemic of black chaff developed naturally in 1934 and 1935. This gave the writer an opportunity to study the genetic nature of resistance to black chaff. The data given in Tables 3 and 4 show this character to be even more variable than that for stem rust reaction. Marquis×H44, III–31–7, Hope, and H44 were moderately susceptible, while the Double Cross, II–21–80, and Pentad×Marquis, III–34–1, were apparently resistant. Segregation was present in the crosses Marquis×H44, III–31–7,×Minn. Double Cross, II–21–80; Pentad×Marquis, III–34–1,×H44; and Pentad×Marquis, III–

TABLE 4.—*Reaction to black chaff of parents, F_1, F_2, and backcrossed plants in 1934 and 1935.*

Parents and generations	Year	No. of plants showing indicated reaction		
		T	M	Total
Pentad×Marquis, III–34–1	1934	5	—	5
Pentad×Marquis, III–34–1	1935	82	—	82
Minn. Double Cross, II–21–80	1934	5	—	5
Minn. Double Cross, II–21–80	1935	74	—	74
Hope	1934	—	11	11
Hope	1935	2	97	99
H-44	1934	2	16	18
H-44	1935	3	61	64
III–34–1×II–21–80, F_1	1934	14	—	14
III–34–1×II–21–80, F_2	1935	521	1	522
Pentad×Marquis, III–34–1×F_1	1935	27	—	27
Minn. Double Cross, II–21–80×F_1	1935	38	—	38
Pentad×Marquis, III–34–1×Hope, F_1	1934	1	4	5
Pentad×Marquis, III–34–1×Hope, F_2	1935	102	179	281
Pentad×Marquis, III–34–1×F_1	1935	51	27	78
Hope×F_1	1935	2	53	55
Pentad×Marquis, III–34–1×H-44, F_1	1934	6	5	11
Pentad×Marquis, III–34–1×H-44, F_2	1935	208	349	557
Pentad×Marquis, III–34–1×F_1	1935	33	25	58
H-44×F_1	1935	11	59	70

34-1 × Hope, whereas most of the plants of the crosses Marquis × H44, III-31-7 and H44 and Marquis × H44, III-31-7 × Hope were moderately susceptible and only one out of several hundred hybrid plants of the cross Minn. Double Cross, II-21-80, × Pentad × Marquis, III-34-1, was moderately infected with black chaff, the rest being apparently resistant. The reaction shown by the F_1 plants of the different crosses indicated that susceptibility was dominant to resistance.

It seems undesirable to attempt a genetic explanation of the manner of reaction to black chaff, but the data clearly demonstrated that resistance and susceptibility were definitely inherited and furthermore showed a general agreement with the conclusions of Bamberg (2), Ausemus (1), and Hayes *et al.* (4).

A study was made to determine the extent of association, if any, between reaction to stem rust and black chaff. The data were analyzed by X^2 for independence and the results are given in Table 5.

The X^2 values of different crosses indicated that association was present. Resistance to stem rust was associated with susceptibility to black chaff. Hybrid plants that are resistant to both diseases were obtained showing association was not complete, but no single plant susceptible to both was found.

TABLE 5.—*Results of X^2 test for independence between reaction to stem rust and black chaff.*

Crosses or generations	Year	D/F	X^2 value
Marquis × H44, III-31-7 × Minn. Double Cross, II-21-80, F_2	1934	2	57.8
Marquis × H44, III-31-7 × Minn. Double Cross, II-21-80, F_2	1935	2	210.7
Marquis × H44, III-31-7 × F_1, (Marquis × H44)	1935	2	58.9
Minn. Double Cross, II-21-80 × F_1, (III-31-1 × II-21-80)	1935	1	34.5
(III-31-1 × II-21-80), F_3	1934	12	117.5
(III-31-1 × II-21-80), F_4	1935	8	71.7
Pentad × Marquis, III-34-1 × Hope, F_2	1935	2	195.5
Pentad × Marquis, III-34-1 × F_1, (III-34-1 × Hope)	1935	2	41.8
Pentad × Marquis, III-34-1 × H44, F_2	1935	2	335.3
Pentad × Marquis, III-34-1 × F_1, (III-34-1 × H44)	1935	2	36.5

SUMMARY

1. Crosses were made of Marquis × H44, III-31-7, and Pentad × Marquis, III-34-1, with Minn. Double Cross, II-21-80, Hope, and H44 to study the inheritance of reaction to stem rust and black chaff.

2. Resistance to stem rust appeared to be dominant to semi-resistance.

3. The data indicated that Marquis × H44, III-31-7 carries a single dominant gene which is allelomorphic to that carried by Hope and H44 and that Minn. Double Cross, II-21-80 carries two complementary factors for semi-resistance similar to those carried by Pentad × Marquis, III-34-1.

4. Susceptibility to black chaff appeared to be dominant to resistance.

5. Resistance to stem rust was associated with susceptibility to black chaff, but the association was not complete; however, no single plant was found that was susceptible to both diseases.

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RESISTANCE OF CORN SEEDLINGS TO HIGH TEMPERATURES IN LABORATORY TESTS[1]

E. G. HEYNE AND H. H. LAUDE[2]

HIGH temperature is a major factor in limiting crop production in semi-arid regions of the United States. These regions have been subjected periodically to droughts, and in severe years complete crop failures have resulted. Weather records indicate that such seasons may be expected to recur. The resistance to high temperature and deficient moisture is an important factor to consider in the development of new varieties for semi-arid regions.

Crops that are generally grown in the semi-arid regions probably have factors that contribute to the ability of the plants to endure high temperatures and deficient moisture. High temperatures are closely associated with a deficiency of moisture in Kansas, and corn adapted to Kansas conditions probably has factors for resistance to both high temperatures and deficiency of soil moisture.

Seasonal conditions fluctuate widely from year to year in the Great Plains area. Since drought and extremely high temperatures do not occur every year, controlled laboratory equipment in which natural conditions can be simulated is an important aid in plant research.

Several investigators have shown the possibility of using controlled high temperatures to distinguish species or strains of plants that are most likely to succeed under natural drought conditions.

This paper reports a study of the effect of several factors on seedling heat susceptibility and gives a comparison of the relative drought tolerance of inbred lines of corn in the field with the seedling behavior of the same inbred lines under controlled conditions in a heat chamber.

MATERIALS AND METHODS

In the summer of 1936, when a severe drought occurred in Kansas, detailed notes were taken on the drought reaction of the strains of corn in the breeding nursery at Manhattan. The strains were classified as resistant, intermediate, and susceptible to drought. Many of these strains were later tested under controlled high temperature conditions to compare with the field behavior.

Before attempting a detailed study of differences between varieties and strains, several experiments were conducted to determine the best conditions and methods for testing corn seedlings.

The room in which the plants were subjected to heat was 5 x 5 x 8 feet. The temperature and humidity were controlled automatically. A constant circulation of air was maintained. The room was dark but could be lighted if desired. The corn was planted in 4-inch, unglazed clay pots containing a uniform soil mixture.

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[1]Joint contribution from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Contribution No. 295 from the Department of Agronomy. Received for publication December 2, 1939.

[2]Junior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; and Agronomist, Kansas Agricultural Experiment Station, respectively. The authors are indebted to Dr. A. M. Brunson for strains of corn used in making these studies.

Enough seed was planted in each pot to insure a uniform stand of seven plants per pot. Sixty-four 4-inch clay pots of corn could be tested at one time and these pots placed on a slatted table. Four or more pots of each strain were distributed at random in the heat room for each test.

Plant height and number of plants per pot were recorded before the treatment. The amount of injury caused by the treatment was estimated the third day after the test and was expressed as the percentage of exposed leaf and sheath tissue that had been killed. The tenth day after treatment the number of plants killed was recorded and notes were taken as to the degree of recovery of the remaining plants.

EXPERIMENTAL RESULTS

AGE OF SEEDLINGS

Hunter, Laude, and Brunson (3)[3] tested 14-day-old corn seedlings at 140° F for 5 hours and obtained differential injury between strains of corn. These same strains were subjected to similar conditions in the present experiment but when the plants were 20 days old. These 20-day-old seedlings were so severely injured that nearly all the plants of the strains tested died.

The greater injury to the older plants suggested that the age of the seedling may have some effect upon the ability of the plant to withstand high temperatures. To study this question, corn planted at 2-day intervals was tested when the plants ranged from 10 to 28 days old. The plants of various ages were all treated at the same time. Representative plants ranging from 12 to 22 days old at the time of treatment are shown in Fig. 1. The 10-day-old plants were very

Fig. 1.—Heat tolerance of corn seedlings at different ages. The numbers refer to the age of the seedlings in days from planting to treatment. All plants were subjected to high temperature at the same time.

resistant and those 14 days old were only slightly less resistant to heat. Plants 16 to 20 days old were very susceptible. After 22 days resistance was somewhat greater as shown by the smaller percentage

[3]Figures in parenthesis refer to "Literature Cited", p. 126.

of dead plants, and it increased slightly thereafter with age. In Fig. 2 the percentage of dead plants and injury are shown graphically for plants ranging from 10 to 26 days old. The older plants were at some disadvantage because of the small size of the pots. In all the strains tested the 10- to 12-day-old plants were more resistant to heat than those 16 to 20 days old.

A study was made of the stored food reserves in the seed at intervals after planting to learn whether the amount of reserves remaining might be associated with heat resistance at different ages. Thirty kernels were weighed and planted at intervals of 2 days in large pots filled with sand. When the age of the plants in these pots ranged from

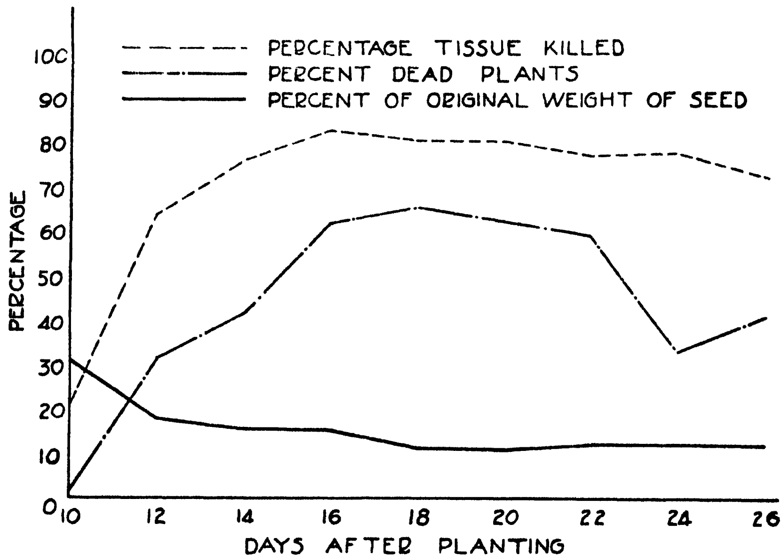

FIG. 2.—Heat tolerance of corn seedlings at different ages as indicated by percentage of dead plants and injured plant tissue. The percentage of the original weight of seeds is also shown.

10 to 28 days, the seed was carefully removed from 20 plants in each pot. The dry weight of the material that remained in the seed is shown graphically in Fig. 2. The decline in weight of seeds was apparently rapid during the first 10 days after planting, as the remaining seed was only 32% of the original weight at that time. From the twelfth to the twenty-eighth day the decline was slight. During the later period the seeds were badly decomposed and were difficult to separate from the soil.

Another study of stored food reserves was made with three strains of corn planted in sand and kept in the dark. The young seedlings were decapitated above the growing point just before the plumule broke through the coleoptile. This process was repeated every day on which one-fourth inch or more growth had occurred. The number of shoots cut off each day was recorded and the percentage was calculated on the basis of the total number of seedlings which germinated.

The results are shown graphically in Fig. 3. There was some fluctuation among the strains in percentage of seedlings decapitated, but after the thirteenth day in two strains and the fourteenth day in the third, the number decapitated daily decreased rapidly. The seedlings of the moderately resistant strain, Hy×R4, failed to send out new growth 18 days after planting. The resistant strain, PS10, grew 1 day longer; the susceptible strain, su51, grew 2 days longer. The resistant strain exhausted the reserve material in the seed at about the same time as the other two strains. Between the tenth and the fourteenth day the plants had apparently used most of the available nutrients in the seed. Soon after this period the plant would be inde-

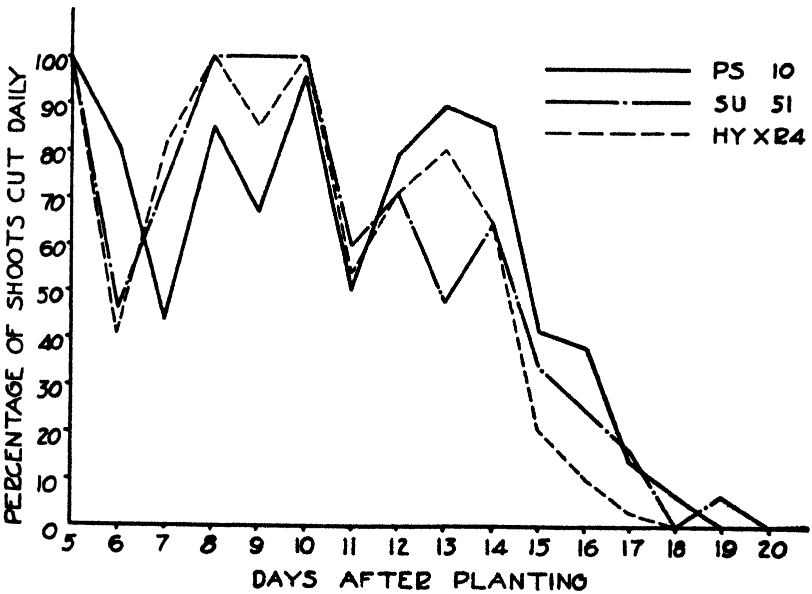

FIG. 3.—Ability of decapitated corn seedlings to send out new growth when grown in the dark. The new shoots were cut back whenever one-fourth inch or more new growth occurred. Three strains of corn were used which differed in heat tolerance.

pendent of the seed for its source of carbohydrates, and probably the available starches and sugars would be at a low level.

Miller (5), in a physiological study of the germination of sunflower seed, found that when the seedling was about 13 days old, it had exhausted all of the nutrients from the seed. When the plants were kept in air free of carbon dioxide for 7 days before this 13-day stage, he noted that several days prior to the end of this period the plants had shown no further growth of their parts.

Suneson and Peltier (6), working with winter wheat plants of various stages of development, found that young wheat seedlings that were presumably still dependent upon the endosperm to a considerable degree surpassed all other more advanced stage-of-development groups in cold tolerance. The present tests with corn have indi-

cated that 20-day-old seedlings of any strain were no longer dependent upon material in the endosperm.

Twenty-day-old corn plants subjected to heat for 5 hours at 130° F and relative humidity ranging from 20 to 30% gave the most satisfactory results for classifying relative high temperature tolerance of different strains of corn. If a longer treatment was given, variations occurred in the rate at which the pots dried during the test. Even though rather large and vigorous plants were tested, it was not necessary to add water during a 5-hour test, provided the pots were well watered before treating.

Although strains of corn vary in kernel size, there was no correlation between small kernel size and heat resistance or susceptibility. Inbred lines of corn often have a small kernel, but some of these small-kerneled strains were more resistant than the larger-seeded varieties and hybrids.

REACTION TO LIGHT

It has long been known that varying exposure to light markedly affects the growth and physiological response of a plant. When corn seedlings were treated early in the morning before they had received any daylight, they were noticeably more susceptible to heat than plants treated in the afternoon under similar conditions. A preliminary note on these and other tests has been published by Laude (4).

On observing this difference in reaction to light, two experiments were set up for a quantitative study of the relation between exposure to light and heat tolerance. In one study, the plants were exposed to various hours of daylight preceded by a period of darkness before being placed in the high temperature room. A series of plants receiving the following combinations of light and dark periods was tested:

Class 0—19 hours darkness; no light.
Class 1—18 hours darkness followed by 1 hour daylight.
Class 2—17 hours darkness followed by 2 hours daylight.
Class 3—16 hours darkness followed by 3 hours daylight.
Class 4—15 hours darkness followed by 4 hours daylight.
Class 5—14 hours darkness followed by 5 hours daylight.
Class 6—13 hours darkness followed by 6 hours daylight.
Class 7—12 hours darkness followed by 7 hours daylight.

Striking differences in heat tolerance were obtained as shown in Fig. 4. The effect of light is shown on two strains, one moderately resistant and the other resistant to heat. The complete series is not shown as there was no significant difference between classes 3 to 7 when Hy×R4 was used and no difference between classes 1 to 7 when PS10 was used. One hour of light, following 12 to 18 hours of darkness, was long enough for the corn plants to acquire considerable resistance to heat. In some cases an increase in resistance to heat was observed when the plants were exposed to light for less than 1 hour following 12 hours of darkness.

To study the rate of loss of heat resistance gained by corn seedlings that were subjected to light, the plants were exposed to various hours of daylight followed by a period of darkness before being placed in

the high temperature room. The plants were in darkness 12 hours before they received any light. The tests to study this question were arranged as follows:

Class 0—19 hours of darkness.
Class 1—12 hours darkness, 1 hour daylight, and 6 hours darkness.
Class 2—12 hours darkness, 2 hours daylight, and 5 hours darkness.
Class 3—12 hours darkness, 3 hours daylight, and 4 hours darkness.
Class 4—12 hours darkness, 4 hours daylight, and 3 hours darkness.
Class 5—12 hours darkness, 5 hours daylight, and 2 hours darkness.
Class 6—12 hours darkness, 6 hours daylight, and 1 hour darkness.
Class 7—12 hours darkness, 7 hours daylight.

FIG. 4.—Effect of light on the heat tolerance of corn seedlings receiving different periods of light and darkness. The four pots to the left are plants of Hy×R4 receiving 0, 1, 3, and 7 hours of light, respectively, and the three pots to the right are plants of PS10 receiving 0, 1, and 7 hours of light, respectively. All plants are of the same age and were treated at the same time.

These classes were subjected to high temperature at the same time so that the conditions of heat and humidity were identical for all the plants tested. Fig. 5 shows that plants which received no light were the most susceptible to heat. Other strains reacted the same as PS10, the strain shown in the illustration, except that strains susceptible to heat did not show as rapid a response to light as the resistant strains. The loss of heat resistance in plants when exposed to darkness, after receiving light, was slower than the gain of resistance in the presence of light.

This quick response to light may have a direct relation to the photosynthetic process which is dependent upon light. Dexter (1) has shown that light has a profound influence on hardening winter wheat plants against cold. Plants deprived of carbon dioxide would not harden under any circumstances, which shows that photosynthesis is involved in hardening plants. He concluded that the development

and maintenance of a high available carbohydrate supply, with retarded vegetative growth, is essential before cold-temperature reaction of hardening of plants will occur in an efficient manner. Tysdal (7) observed that light was an important factor in the cold-hardening process of alfalfa. Plants exposed 16 hours in the hardening room and to 8 hours in a warm greenhouse during daylight developed more hardiness than did those subjected to continuous temperatures. Duggar (2), in reviewing the effects of light intensity upon seed plants, stated that work had been done which indicated that plants developed in the shade are less resistant to drought than those grown in full sunlight.

FIG. 5.—Effect of light on the tolerance to high temperatures of corn seedlings in which the plants received various periods of light followed by darkness. The numbers refer to the class combinations of light and dark periods.

OBSERVATIONS ON INBRED LINES

Approximately 50 inbred lines of corn were tested for tolerance to controlled high temperature. The field reaction of most of the lines was known from their behavior in the drought of 1936. Only a few lines were classed as highly drought-resistant in the field. Most of the lines were classed as intermediate, and it was difficult to rank them accurately as to drought resistance. A few were classed as non-drought-resistant. The latter class was small because of previous elimination during dry, hot years in Kansas.

In order to determine differential response of corn seedlings to controlled high temperatures and humidity it is necessary to subject all seedlings to the same conditions preceding the test. Differences between varieties, lines, and hybrids were the most consistent when 18- to 20-day-old plants were tested for 5 hours at a temperature of 130° F and a relative humidity of 25 to 27%. The plants were supplied with sufficient water prior to the tests to keep the soil moist throughout the 5-hour period.

Although the amount of injury varied with each test, the rank of the lines with respect to injury remained nearly constant. PS10 was included in all tests, making it possible to compare lines in the different tests. Only a few strains were highly resistant in the high temperature tests, the greater portion being intermediate in resistance to heat. These results agreed closely with the observations made in the field.

The inbred lines apparently became subject to damage by heat at definite temperatures. Some lines when subjected to temperatures of 120° F were resistant but were susceptible to slightly higher temperatures. The leaves began to curl on some lines 15 minutes after the test was started, while in others no apparent injury was observed until near the end of the test, when they became severely injured in a short time. A few lines showed dried leaf tissue within one-half hour after the test was started, but after this first brief period of susceptibility they remained unchanged during the remainder of the test. This sensitivity to small temperature changes was observed in the field in 1937. Two lines susceptible to burning of the top leaves were injured by the hot weather. The leaves of most of the plants in one line curled during midday, and, when the temperature increased to 110° F, the top leaves were killed. When the temperature was as high as 112° F, the second line was injured. In both lines the top three leaves were killed, but the plants were still in a vigorous growing condition and recovered when a 2-inch rain occurred several days later. This injury was visible throughout the season.

The reaction of mature corn in the field to drought and of seedlings tested under controlled high temperatures is shown in Table 1. The data include observations made in the field and an average of four laboratory tests with seedlings of 11 strains. All strains were subjected to heat at the same time. This group represents a wide range of inbred types as to time of maturity, height, color of grain, ear type, disease reaction, and years of self-pollination. The first four strains are white. Pride of Saline is an open-pollinated, white corn that is well adapted in Kansas. The YS strains and Mid 1 are yellow and BS 1 is an inbred line selected from Blue Squaw flour corn.

TABLE 1.—*Reaction of strains of corn to drought in the field and to controlled high temperature.*

Strain	Mature plants in field, 1936		Seedling plants under controlled high temperature		
	Drought behavior	Maturity	% injury	% dead	Recovery notes
PS10	Very good	Medium	44	0	Rapid
PS11	Poor	Early	100	70	Slow
PS55	Fair	Medium	97	38	Good
Pride of Saline	Fair	Late	68	20	Rapid
YS148	Very good	Late	58	9	Rapid
YS151	Poor, top-fire	Early	88	14	Rapid
YS164	Poor	Late	100	59	Slow
YS166	Fair	Medium	78	8	Rapid
YS174	Good	Late	95	70	Very slow
Mid 1	Good	Late	81	7	Rapid
BS 1	Escape	Very early	91	38	Slow

The strain YS174 is the only one which under controlled conditions did not react as expected from the field behavior to drought. This inbred occurred in the best single crosses in 1935 with respect to drought resistance. A possible explanation for the high injury of the seedlings

of YS174 from heat may be its aberrant seedling growth. The seedlings of this line have yellow striations on the leaves, which may be a type of chlorophyll deficiency. The rate of growth is slow until it becomes about 18 inches high, and at this time it becomes a uniform green color and begins to grow vigorously.

PS10 and YS148 were considered to be the best inbreds in drought reaction in the field and they also were the best when subjected as seedlings to high temperature. PS55 does not appear to be desirable from the data obtained on seedlings under controlled conditions, but it does have a fairly good field record.

The reaction of YS151 to drought in the field and laboratory is interesting. This inbred line appears to be vigorous in the field under normal growing conditions. However, when high temperatures occur, it begins to top-fire. If after two or three of the top leaves are dried by the heat moisture and cool conditions occur, this line will continue growth. If this burning occurs before the tassel has emerged and favorable weather conditions return, the plant will continue growth, shed viable pollen, and produce grain. The data in Table 1 show that YS151 had a high percentage of tissue killed but a relatively low percentage of dead plants. All the exposed leaf and sheath tissue could be burned at the time of treatment, but one week later the same plant might be growing vigorously. In this case there was a close agreement between the field behavior of older plants and behavior of seedling plants under controlled conditions.

The high temperature room may well be used to study hybrid populations that are segregating for heat tolerance. Fig. 6 shows the segregation of heat tolerance in closely related material. M2 is a resistant inbred which was crossed with a susceptible strain, T4–6a, a sugary translocation. The F_1 of this cross, which is not shown, was outcrossed to another susceptible sugary strain (third pot from left). The resulting cross gave a 50–50 segregation of starchy and sugary

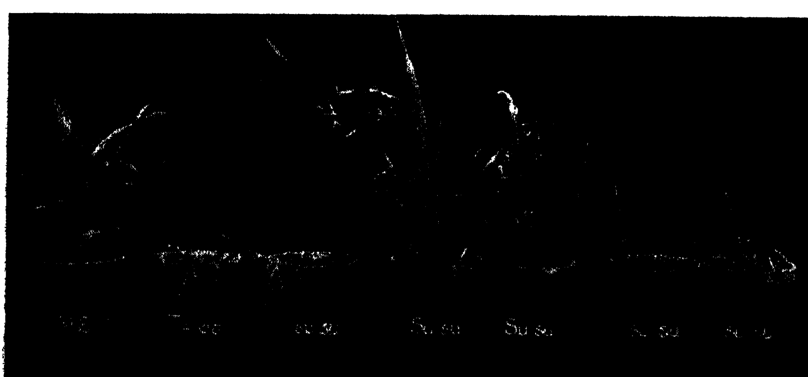

FIG. 6.—Segregation for heat tolerance in cross between resistant and susceptible strains of corn. M2 is the resistant parent, T4–6a the susceptible parent; *susu* (third pot from left) is the susceptible stock to which the F_1 of the above cross was outcrossed. The four pots on the right are the segregates of the plants from starchy (*Susu*) and sugary (*susu*) kernels.

kernels. The plants labeled *Susu* came from the starchy segregates and those labeled *susu* came from the sugary segregates. All plants shown in the illustration were planted and subjected to high temperatures at the same time. The starchy segregates were more resistant to high temperatures than were the sugary segregates. A manuscript is in preparation which discusses the genetics of heat tolerance in corn.[4]

DISCUSSION

Since the corn crop is much influenced by variable weather conditions, an improvement program should be directed toward producing inbred lines and hybrids that will withstand unfavorable growing seasons.

When the growing season is favorable for corn production, little if any progress can be made in selecting strains of corn that are superior in drought resistance. The use of a high-temperature room can then supplement field studies. The reaction of about 90% of the inbred lines of corn subjected to controlled high temperatures was in accord with their known field behavior in Kansas. Only one inbred line differed widely in laboratory reaction and field reaction. All lines that appeared poor in the field were poor also in laboratory trials. Thus, by discarding on the basis of their behavior in the high temperature room, all the poor lines would have been eliminated. Most of the strains that were good in the field also were good under controlled conditions. Using the results of the high temperature room, a large percentage of the more desirable heat-resistant strains would be retained. However, it is believed that information obtained by subjecting corn seedlings to high temperatures should be used only to supplement field studies.

Some lines of corn may have many desirable characteristics but still be susceptible to dry, hot conditions. YS151, the line discussed previously, which top-fired in the field but continued to grow when favorable conditions occurred soon enough, could probably be improved by backcrossing. This line appears promising in crosses, except for top-firing, has good vigor, and produces a desirable kernel for an inbred. It might be improved by crossing with a drought-resistant line and through several generations of back-crossing the susceptible types probably could be eliminated by subjecting seedlings to a high temperature test.

SUMMARY

The reaction of corn seedlings to artificial heat was studied and this reaction was found to correlate well with the behavior of the same strains under field conditions. Seedlings 10 to 14 days old treated for 5 hours at 130° F, with a relative humidity of 25 to 30%, were more heat tolerant than those at the later stages of early development.

Decapitation experiments and decline in weight of seeds indicate that after the fourteenth day the young plants had exhausted most of the food material from the endosperm.

[4]Association between drought resistant factors and certain linkage groups in maize. E. G. Heyne and A. M. Brunson.

The heat resistance of corn seedlings kept in the dark for 12 to 18 hours was increased considerably by exposure to light for as short a period as 1 hour.

The results indicate that the testing of seedlings for heat resistance can be relied upon with considerable assurance for distinguishing genetic differences in the drought tolerance of larger plants of different strains of maize.

A high temperature test apparently is a valuable supplement to field studies of drought resistance.

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GENETIC STUDIES OF RESISTANCE TO ALFALFA MOSAIC VIRUS AND OF STRINGINESS IN *PHASEOLUS VULGARIS*[1]

B. L. WADE AND W. J. ZAUMEYER[2]

THE investigations included in this paper deal with the genetic results obtained with a cross of bean varieties in which reaction to an alfalfa mosaic virus and stringiness were studied. It has been shown by Zaumeyer and Wade (6)[3] that varieties of beans may be designated as resistant or susceptible to an alfalfa mosaic virus, which was later designated as alfalfa virus 1 (7).

Various genetic studies of stringiness have been completed in which simple and more complicated explanations have been used. A single factor difference with stringless dominant over stringy was found by Emerson (2) and by Wellensiek (5), while a segregation in the F_2 of 15 stringless to 1 stringy was found by Prakken (4). On the other hand, there was some evidence for the dominance of stringiness over stringlessness found by Currence (1), Emerson (2), and Joosten (3). Currence (1) reported two types of stringiness, one in which stringiness was due to two dominant complementary genes, and the other in which an incompletely dominant gene for stringlessness was accompanied by an inhibiting factor. Joosten (3) distinguished ten classes of stringiness.

MATERIAL AND METHODS

The crosses involved were of pure lines of Corbett Refugee designated as Mosaic Resistant Refugee Rogue and of Idaho No. 1 Mosaic-Resistant Great Northern. The F_1 of these crosses was very prolific so that all F_2 seed used came from two plants; the A strain, in which the Mosaic Resistant Refugee Rogue was used as the female parent; and the B strain, in which Idaho No. 1 Mosaic Resistant Great Northern was used as the female parent. In order to simplify the designations, these parents are hereafter referred to as Refugee Rogue and Great Northern.

The Refugee Rogue strain used is resistant to alfalfa mosaic virus 1 under conditions prevailing during the tests at Charleston, S. C., and is stringless. Under the same conditions the strain of Great Northern used is susceptible to the virus and is stringy.

The virus used was taken originally from alfalfa, inoculated to peas (*Pisum sativum* L. var. Laxton Progress), then to petunia (*Petunia hybrida* Vilm.) Inoculations in the spring were made from a mixture of about 5% expressed juice from alfalfa and 95% from peas, but inoculations in the fall were made from a mixture of about 5% expressed juice from alfalfa, 15% from peas, and 80% from petunia.

The F_1 from these crosses were not inoculated with alfalfa mosaic virus and notes were not made on stringiness. The F_2 and parents were planted at Charleston, S. C., in the spring of 1938 and inoculated on the seventh day after emergence.

[1]Contribution from the Division of Fruit and Vegetable crops and diseases, U. S. Dept. of Agriculture. Received for publication December 4, 1939.

[2]Senior Geneticist and Pathologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 134.

A fine pumice stone powder was sprinkled on the primary leaves and a block exactly 1 inch square was held under the leaf while the upper surface immediately over the block was rubbed with a cloth saturated in juices from alfalfa-mosaic-virus infested plants. In order to have results as comparable as possible, all inoculating was done by one person and an attempt was made to apply a fairly uniform light pressure to an area of approximately 1 square inch.

The F_3, parents, and a small remnant of F_2 were planted at Charleston, S. C., in the fall of 1938 and inoculations made as before, except that one other worker was necessary in order to cover the material quickly.

The number of local lesions per inoculated leaf was recorded for each plant one week after inoculation. Stringiness was designated by letters, A indicating strong string, B medium, C weak, D trace, and E none.

RESULTS

In order to determine the best method of inoculation, 50 plants of Great Northern were inoculated using approximately 25 grams pressure, and the same numbers at 50 and 75 grams, respectively. The light pressure gave an average of 10.1 ± 0.81 local lesions; the medium pressure 12.2 ± 0.53 lesions; and the heavy pressure, 10.4 ± 0.92 lesions. It was therefore decided to use the medium pressure, although the differences involved were not statistically significant.

Due to a severe frost it was impossible to obtain any seed from the progenies grown in the fall of 1938 and several were killed before they had attained sufficient development of pods to determine whether or not they were stringy or stringless.

INHERITANCE OF RESISTANCE TO ALFALFA MOSAIC VIRUS

Table 1 shows a summary of the results obtained in F_2 and F_3 from plants inoculated with alfalfa mosaic virus 1. From a total of 444 F_2 plants examined, 20 were found to be infected and 424 healthy. On the basis of an expected 15 resistant to 1 susceptible, $X^2 = 3.114$, there was a non-significant deviation. In the F_3, 79 progenies segregating in 15:1 ratios gave a total of 2,344 resistant to 145 susceptible with $X^2 = 0.765$. If these F_2 and F_3 ratios are added together, a ratio of 2,768:165, $X^2 = 1.951$ is obtained.

The F_3 families themselves furnish additional evidence in favor of the 15:1 hypothesis. One hundred thirty F_3 families were found to be entirely free from lesions of the alfalfa mosaic virus, while 79 gave 15:1 ratios, 79 gave 3:1 ratios and 15 were fully susceptible to the virus. The X^2 value for 303 families with 3 degrees of freedom is 0.976, based on a 7:4:4:1 expectation.

The 79 families segregating in ratios of 3 resistant to 1 susceptible gave a total of 1,554 resistant to 474 susceptible plants, with $X^2 = 2.864$.

Table 1 further shows that there are no significant differences between the cross and its reciprocal insofar as reaction to alfalfa mosaic virus is concerned.

The alfalfa-mosaic resistant parent planted at regular intervals throughout the plots remained free from lesions while in all cases the susceptible parent showed lesions.

TABLE 1.—*Results obtained with F_2 and F_3 progenies from the cross (A) Mosaic Resistant Refugee Rogue×Idaho No. 1 Mosaic Resistant Great Northern and (B) reciprocal, when inoculated with alfalfa mosaic virus 1.*

F_2 generation

When grown*	Resistant plants	Susceptible plants	X^2†
A Strain			
S	155	8	0.501
F	79	3	0.940
B Strain			
S	157	7	1.099
F	33	2	0.017
Total	424	20	3.114

F_3 generation families

When grown*	Resistant plants	15:1	3:1	Susceptible plants	X^2	D.F.‡
A Strain						
F	60	42	39	8	1.175	3
—	—	—	—	—	—	—
B Strain						
F	70	37	40	7	1.098	3
—	—	—	—	—	—	—
Total	130	79	79	15	0.976	3

F_3 segregating progenies

Strain	No. families	When grown*	X^2§	D.F.	No. resistant plants	No. susceptible plants	X^2
15 resistant: 1 susceptible							
A	42	F	8.655	42	1,134	70	0.391
B	37	F	12.425	37	1,210	75	0.375
Total	79		21.080	79	2,344	145	0.765
3 resistant: 1 susceptible							
A	39	F	19.464	39	764	230	1.071
B	40	F	8.899	40	808	244	1.830
Total	79		28.363	79	1,554	474	2.864

*S indicates spring grown; F fall grown.
†None of the above X^2 values exceed the 5% point.
‡When degrees of freedom (D.F.) are 1 for a given ratio, they have been omitted.
§X^2 added from individual progenies with 1 degree of freedom for each progeny.

INHERITANCE OF STRINGINESS

Table 2 shows a summary of the results obtained in F_2 and F_3 when stringiness was studied. Two hundred eleven F_2 plants were stringless and 150 stringy, X^2 equals 0.709 based on a 9:7 ratio. In arriving at stringiness and stringlessness it was found that A, B, and C types should be classed as stringy and D and E as stringless. This was borne out by F_3 results. In the F_3, 59 progenies segregating in 9:7 ratios gave a total of 693 stringless to 535 stringy: X^2 equals 0.015. When the F_2 and F_3 plants, for 9:7 ratios are added, the ratio becomes 904:685, and X^2 equals 0.261.

On the basis of an expectation of 1 stringless, 4 segregating 3 stringless to 1 stringy, 4 segregating 9 stringless to 7 stringy, and 7 stringy families in F_3, a X^2 of 7.720 for 3 degrees of freedom was obtained. However, when this X^2 was corrected for continuity the value was reduced to 6.895. The observed values are 26:69:59:103 F_3 families.

The 69 families giving a ratio of 3 stringless to 1 stringy in F_3 gave an actual ratio of 1,026:306, and X^2 equals 2.919.

Table 2 shows that there is no significant difference between reciprocal crosses insofar as stringiness is concerned.

LINKAGE STUDIES

Table 3 shows the results obtained when F_3 X^2 values for linkage were computed for resistance to alfalfa mosaic virus and stringiness. In no case did the value obtained indicate that the 5% point of probability was exceeded.

Linkage determinations based upon the combined F_2 from the cross and its reciprocal gave a linkage X^2 value of 0.302 based on frequencies of 198 healthy stringless: 13 virus infected stringless: 143 healthy stringy: 7 virus infected, stringy. X^2 for the cross (A) was 1.076, for the reciprocal (B) 0.069.

On the basis of these observations it is concluded that there is no evidence of linkage between any of the four pairs of factors involved in the expression of these characters. Chi square for the combinations of ratios used indicated that no exceptionally variable ratios were encountered (last two columns Table 3).

DISCUSSION

The results obtained in this study of the genetics of alfalfa mosaic virus are fully in accord with the original study of Zaumeyer and Wade (6) in which it was found that Great Northern was susceptible to alfalfa mosaic virus while Corbett Refugee was resistant. However, there is an apparent discrepancy between these results and those reported later by Zaumeyer (7), in which both varieties were found to be moderately susceptible to alfalfa mosaic virus 1. It seems worth while to point out that there is considerable difference in the technics and strains used for an analytical genetic study compared to those used in a variety test of host range in a pathological study. It is probable that in the following possible explanations there may be found the reason for the apparent conflict with the later publication (7):

TABLE 2.—*Results obtained with F_2 and F_3 progenies from the cross (A) Mosaic Resistant Refugee Rogue × Idaho No. 1 Mosaic Resistant Great Northern and (B) reciprocal Classified in stringless and stringy classes.*

F_2 generation

When grown*	No. plants stringless	No. plants stringy	X^2†
	A Strain		
S	92	71	0.221
F	12	6	0.794
	B Strain		
S	96	68	0.348
F	11	5	1.702
Total	211	150	0.709

F_3 generation families

When grown*	Stringless	3 stringless: 1 stringy	9 stringless: 7 stringy	Stringy	X^2	D.F.‡
			A Strain			
F	13	27	26	49	5.104	3
—	—	—	—	—	—	—
			B Strain			
F	13	42	33	54	4.346	3
—	—	—	—	—	—	—
Total	26	69	59	103	7.720	3

F_3 segregating progenies

Strain	No. families	When grown*	X^2§	D.F.	No. stringless plants	No. stringy plants	X^2
		9 stringless: 7 stringy					
A	26	F	17.584	26	299	222	0.275
B	33	F	22.136	33	394	313	0.083
Total	59	F	39.720	59	693	535	0.015
		3 stringless: 1 stringy					
A	27	F	14.168	27	487	145	1.426
B	42	F	8.278	42	539	161	1.493
Total	69	F	22.446	69	1,026	306	2.916

*S indicates spring grown; F fall grown.
†None of the above X^2 values exceed the 5% point.
‡When degrees of freedom (D.F.) are 1 for a given ratio, they have been omitted.
§X^2 added from individual progenies with 1 degree of freedom for each progeny.

TABLE 3.—*Chi square values for determination of association or linkage between ratios obtained from F_3 segregating progenies for resistance to alfalfa mosaic virus 1 and stringlessness, from the cross (A) Mosaic Resistant Refugee Rogue×Idaho No. 1 Mosaic Resistant Great Northern and (B) reciprocal.*

Cross	Number of plants				Ratios*	Association or linkage X^2†	D.F.	Linkage X^2 added from individual progenies	D.F.	Linkage X^2 differences	D.F.
	Alfalfa-virus resistant Stringless	Alfalfa-virus susceptible Stringless	Alfalfa-virus resistant Stringy	Alfalfa-virus susceptible Stringy							
A	137	8	103	7	15:1 and 9:7	0.078	1	11.416	10	11.338	9
B	92	4	81	3		0.059	1	12.097	10	12.038	9
Total	229	12	184	10		0.003	1	23.513	20	23.510	19
A	90	3	18	2	15:1 and 3:1	1.290	1	7.076	5	5.786	4
B	95	8	26	3		0.172	1	12.181	7	12.009	6
Total	185	11	44	5		1.158	1	19.257	12	18.099	11
A	46	7	31	9	3:1 and 9:7	1.099	1	3.257	5	2.158	4
B	14	5	14	2		0.943	1	3.484	4	2.541	3
Total	60	12	45	11		0.149	1	6.741	9	6.592	8
A	127	35	41	13	3:1 and 3:1	0.132	1	3.522	6	3.390	5
B	140	53	50	12		1.621	1	15.412	15	13.791	14
Total	267	88	91	25		0.478	1	18.934	21	18.456	20

*In each case the ratio for resistance vs. susceptibility to alfalfa-mosaic virus is given first, followed by the ratio of stringlessness vs. stringy.
†None of the above X^2 values exceed the 5% point.

1. In dealing with Corbett Refugee originally (6, 7) no effort was made to use pure lines, while in the study reported here only two single parent plants were involved. It is quite possible that a single plant picked out of a variety may have some characteristics different from the mean of that line. The number of plants tested in previous studies have been small so that the results reported cannot be expected to be rigidly applicable to large numbers of plants in a pure line selected from the original parent strain. As a matter of fact, in the original study (6) there was an indication that the Great Northern was heterogeneous for susceptibility and resistance since only 3 out of 10 were infected. The different results reported for Corbett Refugee (6, 7) may merely indicate heterogeneity. The results are presented in a different way in the later publication (7), but the total lesions for 10 plants inoculated in each case with three strains of alfalfa mosaic virus 1 we find that 30 Corbett Refugee plants produced 343 lesions while the same number of Great Northern plants produced 778 lesions. This is an average of 11.43 and 25.93 lesions, respectively. At Charleston the best technic for the Great Northern gave an average of 12.2 lesions, or a reduction of 13.73 lesions per plant. If the same absolute reduction held true for the Corbett Refugee, assuming a mixture of the three types of alfalfa mosaic virus, then that variety would be expected to be resistant under Charleston conditions.

2. In previous studies (6, 7) the inoculum used was taken from alfalfa plants infected with alfalfa mosaic virus 1, while in this study only a small portion of alfalfa juice was used. The possible influence of the other plant juices on infection may have to be taken into consideration.

3. Pure lines of the alfalfa mosaic virus 1 are not available and each time a study has been made of it new collections from alfalfa have been made. Slight changes in the virus may result in a considerable change in the ability of the virus to infect various host strains and varieties.

4. In pathological studies of the virus (6, 7) no abrasive was used in the inoculations while in this study finely ground pumice stone was used. The application of virus to thousands of plants must necessarily be done in a quick and dependable way if results are to be comparable. The development of such a technic may result in a change in level of infectivity of the virus, whereby two varieties that are susceptible by a leisurely technic may be differentiated by the large scale method.

5. No adequate studies of the effect of various environments on alfalfa mosaic virus 1 have been made, so that some of the differences encountered may be due to the influence of the environment on the virus, host plants or both. At Charleston the individual local lesions were relatively smaller than those produced near Washington, D. C., there was practically no tendency for coalescence to occur, and the number of lesions per susceptible plant was low.

From work previously done by other investigators (1, 2, 3, 4, 5), it could very well be expected that additional genetic ratios for stringiness vs. stringlessness might be found.

SUMMARY AND CONCLUSIONS

In a cross between strains of Corbett Refugee (Mosaic Resistant Refugee Rogue shortened to Refugee Rogue) and Idaho No. 1 Mosaic Resistant Great Northern (designated here Great Northern) and reciprocal, inheritance of resistance to alfalfa mosaic virus 1 and stringiness of pods were studied.

Genetic observations were made in F_2 and F_3 for both characters. From over 400 F_2 plants and over 300 F_3 families (about equally divided between the cross and its reciprocal), it was concluded that resistance is due in this case to duplicate dominant genes giving a ratio of 15 resistant to 1 susceptible in F_2; and a ratio of 7 resistant to 4 segregating 3:1, to 4 segregating 15:1, to 1 susceptible families in F_3. The statistical constants computed indicated no reason for questioning this hypothesis.

The same plants used in the virus study were classified for stringiness, except that frost destroyed part before they were sufficiently mature for classification. It was found that stringiness in this cross is due to duplicate recessive genes in which the dominant alleles are complementary. Satisfactory fits to a ratio of 9 stringless to 7 stringy were found in F_2; and to a ratio of 1 stringless family, to 4 segregating 3 stringless to 1 stringy, to 4 segregating 9 stringless to 7 stringy, to 7 stringy in F_3.

No linkage or association was found between stringlessness and resistance to alfalfa mosaic virus 1.

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AGRONOMIC RESEARCH PROJECTS[1]

Henry M. Steece[2]

RESEARCH in agronomic fields embracing crop improvement and production, soils, and fertilizers has long occupied a leading position in the programs of the state experiment stations and has composed a substantial part of the activities of the U. S. Dept. of Agriculture. Experimentation in the pioneer years of the experiment stations, made largely in response to local requests for information on immediate practical problems, including for example, variety, cultural, rotation, and fertilizer tests and breeding work with many crops, was usually elementary in nature and of conventional type. The subjects dealt with often appeared simple and possible of solution by a few comparative tests. Many of the problems, however, were more involved than was apparent upon first consideration, and new methods and improved technic were needed for their solution.

During recent years, experiment station agronomists have been giving special attention to more complex and more fundamental problems, such as weather-crop relations; soil-fertility problems associated closely with crop production and plant composition; availability of essential soil nutrients to the plant, effects of their deficiencies, and effective and economical methods of supplying them to crops in fertilizers; vegetative and other methods of soil-erosion control; machine-harvesting problems; crop storage and handling; and factors variously affecting market values and qualities of the several crops. Prominent in present-day agronomic research is the improvement of cereal, fiber, oil-seed, forage, sugar, and root crops and tobacco in yield, resistance to diseases, insects, and adverse environmental factors, and in market and technological qualities. Work in this field usually proceeds in association with research in genetics and cytology. Agronomic phases of the greatly expanded pasture investigations throughout the country are also receiving serious attention.

Many of these problems go far beyond the province of a single institution and have been best coped with by cooperative action among several or many stations and the U. S. Dept. of Agriculture. These broader activities find places in the station programs along with the more fundamental researches that provide information on which to base experimentation with more immediate practical application, and the numerous variety, fertilizer, cultural, and harvesting tests, often more or less conventional or local, yet necessary in the broad industry of agriculture.

RESEARCH ON A PROJECT BASIS

Most of the research in agronomy, as in other fields of agricultural science dealt with by the experiment stations and the U. S. Dept.

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of Agriculture, is on a project basis. This is particularly true for all work financed by allotments from appropriations authorized under the Adams, Purnell, and Bankhead-Jones Acts at the stations and the lines of work proceeding in cooperation with divisions of the Department and other governmental agencies. The formal project as the basis for research and allotment of funds was accepted by general agreement soon after the passage of the Adams Act in 1906.

The research programs of the experiment stations, financed from all sources, have included during the last two or three years approximately 8,500 projects embracing a wide range of agricultural and rural-life problems. About 3,020 of these projects with approved written outlines were supported during the fiscal year 1938–39 by Adams, Purnell, or Bankhead-Jones funds, often with supplemental financing by Hatch and state funds, and included 587 projects in definitely agronomic subjects. These comprised 234 concerned with production of field crops, 37 with crop-plant genetics, 119 with pastures and ranges, and 197 with soils and fertilizers. In addition there were many projects in horticulture, forestry, and plant pathology of interest to agronomists because of the genetics, cultural and field practices, and soil and fertilizer problems involved.

The U. S. Dept. of Agriculture, as represented by the Office of Experiment Stations, is charged with the administration of the several federal funds allotted to the state experiment stations for research, and this has been on the basis of approved projects for the Adams, Purnell, and Bankhead-Jones funds, a procedure agreed to by the Association of Land-Grant Colleges and Universities. Consideration by the Office of Experiment Stations of projects submitted in outline for support from these three federal funds involves much more than simple approval. New projects are subjected to critical examination and analysis before being accepted. Attempt is made to insure clarity and adequacy in the outlines, to make certain that procedures reflect up-to-date developments in research, and to offer any suggestions which might prove helpful. The purpose is always to assist by suggestion and discussion, calling attention to other pertinent investigations, with a desire to encourage and preserve local initiative, and with full recognition of the responsibility of the experiment station for making final decisions.

The formal project usually originates with the leader after conference with the director of the experiment station. The project outline is one of the clearest evidences of a worker's motives, his vision, and his preparation to carry through an investigation. A good outline shows clear thinking, a definite purpose, and a well-determined course of action. Specific objectives and plans of procedure may sometimes be tentative, subject to change with the progress of an investigation but they are essential and give effective direction to the effort.

The problem which the investigation proposes to solve may have its origin in demands from local groups or agencies or in current conditions, such as climatic disturbances, outbreaks of disease or insects, labor shortage, or excess production. It may arise as an offshoot from an investigation in progress, in the recent findings of other agrono-

mists, or it may be an original concept. Slipher[3] recently has indicated considerations attending the recognition and evaluation of research problems. In conclusion he emphasizes, "(1) that skillful identification of the problem is no less a duty of research than is its solution; (2) that problems possess facial appearance, structural breadth, and depth; (3) that the more penetrating tool for exploring the problem lies in the scientific method; and (4) that practicability—though sometimes an objective—is not a method." Regardless of the origin of a problem, there are certain fundamentals which should receive attention in drawing up a research project for its solution.

Experience over three or more decades has shown that the research project is most likely to be effective when it is definite, restricted in scope to what may be accomplished in a reasonable time, and aimed at a few simple objectives; a seasoned, carefully considered enterprise, subjected to prior criticism and suggestion and formulated only after thorough consideration of the status of knowledge on the subject, including previous findings, and where possible the current work of others.

ESSENTIALS OF AN AGRONOMIC RESEARCH PROJECT

The essential points to be covered in a research project outline have been under consideration for many years by the Association of Land-Grant Colleges and Universities. It is their view[4] that "the precise and complete form and content of a project outline, applicable to all cases, would be difficult to prescribe, but adequate and definite information . . . is essential. . . . The project should be designed to undertake thoroughly and with reasonable completeness the investigation of the subject and it should not be fragmentary and superficial." It may be useful to discuss briefly the major considerations in the formulation of adequate research project outlines. The discussion is based on statements made then and modified later and amplified by the writer.

Title.—The title should be a brief, clear, specific designation of the research to be undertaken. Simple indefinite labels, such as Potato Investigations, Wheat Production, or Forage Improvement, may have the merit of brevity, but they fail to characterize the proposed investigation and should be avoided, Unnecessary words, such as "study of" or "investigation of" can well be omitted.

Objectives.—A clear statement of the specific objectives of the project is important. These should be in logical order, should not refer to procedures, and, when more than one objective is stated, they should bear an intimate relation to each other and to the major over-all objective. Some projects, e. g., Weed Investigations, Wheat Production, amount to blanket proposals. They are open to the objection that they do not state a problem but indicate a field; they offer many objectives or an indefinite composite aim.

[3]SLIPHER, J. A. How to recognize and evaluate a research problem. Agr. Eng., 20:309, 310. 1939.

[4]Report of the Committee on Experiment Station Organization and Policy, Assoc. Land-Grant Col. and Univ. Proc., 45:265, 266. 1931.

Reasons for undertaking the study.—The outline should include a statement showing the importance of the problem to agriculture or rural life, the probable use of the results, and the justification for the research under the particular funds designated for its support. U. S. D. A. Miscellaneous Publication No. 348 (June 1939) gives the texts of the several federal-grant acts and their requirements and limitations. Even for the more fundamental researches the statement should set forth the practical agricultural objective of the proposed work so clearly that any intelligent layman can readily understand and appreciate its general purpose. Such information is a requisite for administrators who often may have to explain and defend the different lines of work in progress.

Previous work and present outlook.—A brief summary should cover previous research on the problem (citing the more important publications), the status of current research, and the additional information needed to which the project is expected to contribute. Thorough knowledge of the earlier and current work on the subject of the proposed inquiry is essential in order that needless repetition or duplication of the work of others may be avoided, and also to take account of the most advanced methods. As Allen[6] pointed out 10 years ago, "A research project should start where others have left off or where apparently their work has ended. Repetition and replication may be warranted where aimless duplication is not, but blind repetition without any definite or justified reason and devoid of any new idea is a reflection on imagination and individuality."

The *Experiment Station Record* furnishes a current survey of agricultural research now extending over 50 years, and such publications as *Biological Abstracts*, *Herbage Abstracts*, *Plant Breeding Abstracts*, and *Chemical Abstracts* record progress in specialized branches of agronomic science. Useful reviews of previous work in the field of the problems under consideration often may be found in bulletins and journal articles. The *Journal* of the American Society of Agronomy and *Soil Science* are excellent reporters of results of agronomic inquiry and are useful for the exposition of improved methods of research. The annual reports of the stations usually give progress results from currently active projects. The Office of Experiment Stations endeavors to maintain a classified file of research projects under way at the experiment stations. These are but a few of the many sources of information on the results of research with crops and soils.

Procedure.—An explicit statement should indicate the essential working plans and methods to be employed in attaining each objective, the phases to be undertaken currently, and the facilities and equipment needed and available. The procedure should be adequate, well balanced, and representative of the progress and current views on methods and technic, and ought to show clearly provision for solving each objective. The details of procedure may have to be revised from time to time in line with experience and new information, in which case a new outline is advisable.

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[6]ALLEN, E. W. Initiating and executing agronomic research. Jour. Amer. Soc. Agron., 22:341–348. 1930.

The determination of what data are essential, development of ways to obtain them, and tests of their applicability and significance make up a large part of agronomic research. The natural aim is to obtain relevant and positive evidence extensive enough for critical analysis. Endeavors in this direction may be defeated by all-too-frequent faults in technic, such as inclusion of too many variables, lack of proper checks or basic treatments, disregard of nonuniformity of test soils, inadequate replication, no arrangement for appropriate statistical treatment of results, and failure to consider interplat competition. Technic defective in these respects is inexcusable in agronomic investigation, especially when one considers the many sources of information now available on the subject.

Probable duration.—An estimate of the maximum time probably needed to complete the project and publish results also is of value. The period should not be unduly protracted, although long enough to attain the objectives and report on the findings. When these are accomplished the project is best amended or closed and replaced with a new enterprise. Prolonged projects without changes in plan or objectives all too often become unfruitful and hence are difficult to defend.

Financial support.—The leader should include an estimate of annual allotments (by funds) needed for (1) salaries and (2) maintenance, based on analysis of requirements for salary, labor, equipment, supplies, travel, other operating expenses, and publication. In this connection it is well to keep in mind that while the administration of the institution necessarily must practice economy and good judgment in the allotment of funds to research, inadequate support has been found wasteful and ineffective and often responsible for indifferent and protracted efforts.

Departments involved.—It is of advantage to indicate each of the departments or organized divisions of the institution contributing to the project essential services or facilities and the respective functions and responsibilities of each in the investigations. Attention to this feature will help to obviate possible future misunderstandings.

Personnel.—The leader or leaders and other technical workers assigned should always be shown. It has been found wise, where practicable, to have only one person responsible for an individual phase or study in the project. Prudent administration and assignment of personnel are essential to successful cooperation and to balanced completeness in the undertaking.

Cooperation.—A project statement should give recognition to any formal or informal cooperation involved with the bureaus of the U. S. Dept. of Agriculture or with other experiment stations or institutions and should list the effective date of any memoranda of understanding concerned. The complexity of many of the agronomic problems of today and the trend toward basic research have led agronomists to profit more and more from the experience of workers in other scientific and technical lines, and to use their methods, their findings, and their collaboration in attacking new problems or untouched or unsolved aspects of older inquiries. Many of the research plans may properly involve the functions of two, three, or even more different lines in a

combined attack. This type of cooperation is excellent so long as each participant realizes that the situation is one calling for mutual helpfulness and team play and not a scheme for evading responsibility. The rôle of each should be stated definitely. In cases where the problem and the outlook extend beyond the jurisdiction and the personnel and financial resources of one station, the situation often is best dealt with by each agency setting up a project that forms a part of a cooperative program. Examples of such cooperative efforts on an extensive scale are the national improvement programs involving cereals, fibers, sugar crops, potatoes, and tobacco; the cotton research program covering most aspects of cotton production, marketing, and utilization; and the several active pasture programs.

CONCLUSIONS

Every agronomic research project should be regarded as a joint investment of the leader, the institution, and the public. The returns from the enterprise will depend in part upon the leader, his attitude and ability, and his comprehension of the problem and its needs, and in part upon the administrator, his wise guidance and encouragement, and his ability to arrange for the facilities, operating expenses, personnel, and time essential to its successful prosecution.

RESISTANCE OF F_1 SORGHUM HYBRIDS TO THE CHINCH BUG[1]

R. G. DAHMS AND J. H. MARTIN[2]

THE differential effect of chinch bugs (*Blissus leucopterus* Say) on varieties of sorghum has been reported in detail by Snelling, *et al.* (3).[3] Most sorghum hybrids show high resistance to chinch bug injury in the F_1 generation, but heretofore it has never been possible to determine, except by extensive progeny tests, whether this resistance was genetic or merely a result of the rapid and heavy plant growth usually exhibited by sorghum hybrids. Dahms, *et al.* (1) have shown that, as a general rule, chinch bugs lay more eggs and live longer, and the nymphs develop into larger bugs, on susceptible varieties than on resistant varieties, but that these differences are less marked under field conditions than under laboratory conditions. The laboratory method of determining resistance used heretofore consists in placing a fresh seedling in each cage every day with the roots immersed in water. Such a large number of seedlings are required that studies of the inheritance of resistance have been almost precluded. With this method the production of sufficient crossed seed for the testing of F_1 hybrids is laborious and tests of the F_2 generation are impossible. This handicap has now been eliminated by the development of a method of caging known numbers of bugs on growing plants in the field. The resistance to chinch bug injury is determined by observing the effects of the host upon the development of the insects rather than the effects of the insects upon the host. The presence of factors for resistance apparently may be detected by the use of this method, which is described in this paper.

With the number of eggs laid by, and the duration of life of, chinch bugs confined to plants growing under field conditions as a criterion, the reactions of 11 hybrids in the F_1 generation were measured and certain applications of the data to the problem of breeding for resistance are suggested. Studies of the inheritance of resistance in the F_2 generation are now in progress. The experiments were conducted in 1938 at the U. S. Dry Land Field Station, Lawton, Okla.

MATERIAL AND METHODS

The cages used to confine chinch bugs on plants growing in the field (Fig. 1) consisted of a special type of celluloid tube about 7 cm long and 2.5 cm in diam-

[1]Cooperative investigations between the Oklahoma Agricultural Experiment Station and the Bureaus of Plant Industry and Entomology and Plant Quarantine of the U. S. Dept. of Agriculture. Abstract of a portion of thesis submitted by the senior author to Kansas State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication December 11, 1939.

[2]Assistant in Entomology and Senior Agronomist, respectively. The writers wish to express their appreciation to W. M. Osborn, superintendent of the Lawton, Okla., station of the Bureau of Plant Industry, U. S. Department of Agriculture, for providing facilities for these experiments, and to F. A. Fenton, Oklahoma Agricultural Experiment Station, and P. N. Annand and C. M. Packard, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, for making these experiments possible.

[3]Figures in parenthesis refer to "Literature Cited", p. 147.

eter. A cork stopper covered with muslin cloth was placed in each end of the tube. An ellipsoid hole was cut in the side about midway between the ends of the tube. This hole was covered with muslin which was glued to the celluloid with a special type of water-proof glue. Each tube was fastened crossways on one side of a sorghum stalk, with the muslin-covered hole next to the stalk, by passing a fabric-covered elastic band around the stalk and snapping it over the ends of the tube. Fabric-covered bands were necessary, as plain rubber bands soon became brittle and broke under field conditions. Bugs placed in these cages appeared to have no difficulty in feeding through the cloth. The cages were placed on the north side of sorghum plants and as much in the shade as possible. Under these conditions the temperature ordinarily ranged from 2° to 6° F higher in the cages than outside in the shade.

FIG. 1—Chinch bug cages on sorghum plants in the field.

In these cages fifth-instar nymphs collected in the field were confined on the varieties or hybrids to be tested. First-generation bugs were collected from spring barley and second-generation bugs from Dwarf Yellow milo. When the bugs reached the adult stage, they were paired, and five pairs placed in each cage and three cages on each plant at different heights. In most cases 5 to 10 plants of each variety or hybrid were used. Egg counts were made once each week.

Two plantings of sorghums were made, one on April 30 to be tested with first-generation bugs, and the other on June 27 to be tested with second-generation bugs. Eleven F_1 hybrids and their parents were grown.[4]

EXPERIMENTAL RESULTS

Table 1 shows the percentage of plants killed in the field and the average number of eggs laid per female by chinch bugs, both in the laboratory and under field conditions, on four typical sorghum varie-

[4]The seed of the hybrids and parental varieties was furnished by J. C. Stephens, of the Bureau of Plant Industry, located at Texas Agricultural Experiment Station Substation No. 12, Chillicothe, Tex.

ties. On seedling plants in the laboratory the fewest eggs were laid on feterita, whereas under field conditions more eggs were laid on this variety than on either Blackhull kafir or Atlas sorgo. When the number of eggs laid while the bugs were confined to plants growing in the field was used as a criterion for measuring resistance, the Dwarf Yellow milo was the most susceptible, followed in order by feterita, Blackhull kafir, and Atlas sorgo. These varieties were ranked in this same order when resistance was determined by percentage of plants killed in the field.

TABLE 1.—*Resistance of several varieties of sorghum to the chinch bug, as measured by the percentage of plants killed in the field and by the number of eggs laid per female in the laboratory and in field cages.*

Variety	C. I. No.*	Percentage of plants killed in the field†	Number of eggs laid in laboratory‡	Number of eggs laid in field cages§
Dwarf Yellow milo...	332	100	99.4	188.8
Feterita	182	51	1.7	148.7
Blackhull kafir	71	23	21.2	104.6
Atlas sorgo........	899	13	3.9	97.9

*Accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry.
†Four-year average
‡Average for three generations of bugs, 1936.
§Average for two generations of bugs, 1937.

Oviposition records of chinch bugs feeding on 11 F_1 sorghum hybrids and their parents are shown in Table 2. In most cases more eggs were laid by the second-generation bugs than by those of the first generation. This difference was not very great, however, and the relative resistance of the different varieties for the two generations was very similar. When one or both parents were resistant, the F_1 hybrids also were resistant. One possible exception to this was Texas Blackhull kafir × Day milo, which might be considered as intermediate. The results strongly indicate a dominance of resistance in these crosses. In several cases the hybrid was more resistant than either parent, indicating the presence of complementary cumulative factors for resistance. In crosses between two susceptible varieties the hybrids were susceptible, although an apparent exception to this was feterita × (feterita × milo), in which an average of only 80.8 eggs per female were laid on the feterita parent. This, however, probably was due to the very weak plants that were produced from the seed used.

When the egg data were analyzed statistically by the method of analysis of variance (2), it was found that on the whole the differences in the number of eggs laid on the several varieties and hybrids were highly significant.

The average length of life of chinch bug females (Table 2) feeding on the different varieties ranged from 25.0 days on Texas Blackhull kafir × Dwarf Yellow milo to 46.2 days on feterita. In general, the bugs lived longer when feeding on susceptible than on resistant varieties, but the differences were not very great, and the data are too limited to warrant making general conclusions. The analysis of variance, however, showed that differences in the length of life of females feeding on the several varieties and hybrids were highly

TABLE 2.—*Oviposition and longevity of chinch bug females on 11 F_1 sorghum hybrids and their parents.*

Hybrid or parent	Record No.*	Average number of eggs per female			Average duration of life in days		
		First generation	Second generation	Mean	First generation	Second generation	Mean
Sumac sorgo	S. P. I. 35038	72.1	89.3	80.7	40.0	40.7	40.3
Texas Blackhull kafir × Sumac sorgo	—	44.5	76.0	60.2	25.8	30.5	28.1
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Atlas sorgo	C. I. 899	64.9	80.8	72.8	38.5	31.2	34.8
Atlas × Dwarf Yellow milo	—	67.3	—	—	29.8	—	—
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Feterita × milo	F. C. 8926	194.5	187.7	191.1	43.3	39.8	41.5
Texas Blackhull kafir × (feterita × milo)	—	67.3	—	—	27.1	—	—
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Texas Blackhull kafir × Dwarf Yellow milo	—	73.8	85.5	79.6	28.1	21.9	25.0
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Feterita	C. I. 182	146.7	150.7	148.7	49.5	43.0	46.2
Texas Blackhull kafir × feterita	—	73.1	87.8	80.4	34.7	42.6	38.6
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Darso × Dwarf Yellow milo	—	70.7	92.7	81.7	26.8	25.6	26.2
Darso	F. C. 6606	91.9	95.7	93.8	36.1	32.0	34.0
Texas Blackhull kafir × darso	—	69.4	106.5	87.9	39.0	35.1	37.0
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Texas Blackhull kafir × Day milo	—	100.4	113.1	106.7	37.1	45.5	41.3
Day milo	C. I. 480 × 332–187	106.6	167.2	136.9	39.7	47.1	43.4
Feterita × milo	F. C. 8926	194.5	187.7	191.1	43.3	39.8	41.5
(Feterita × milo) × Dwarf Yellow milo	—	138.6	—	—	39.1	—	—
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Dwarf White milo × Dwarf Yellow milo	—	194.8	169.9	182.3	45.1	40.4	42.7
Dwarf White milo	F. C. 8927	150.2	188.8	169.5	40.4	34.4	37.4
Feterita†	F. C. 811	80.8	—	—	35.5	—	—
Feterita × (feterita × milo)	—	202.8	205.5	204.1	50.0	39.3	44.6
Feterita × milo	F. C. 8926	194.5	187.7	191.1	43.3	39.8	41.5

TABLE 3.—*Height, diameter of stalk, and tillering of 11 F_1 sorghum hybrids and their parents in relation to the number of eggs laid by chinch bugs.*

Hybrid or parent	Record No.	Heterosis	Average height of plant, inches	Average diameter of stalk at base, inches	Average number of stalks per plant	Maturity	Average number of eggs laid per female
Texas Blackhull kafir × Sumac sorgo	————	Medium	70.5	1.06	1.9	Late	60.2
Texas Blackhull kafir × (feterita × milo)	————	Medium	69.0	1.06	2.3	Late	67.3
Atlas sorgo × Dwarf Yellow milo	————	Much	90.7	1.28	4.5	Late	67.3
Atlas sorgo	C. I. 899	————	68.0	0.94	3.5	Late	72.8
Texas Blackhull kafir × Dwarf Yellow milo	————	Much	94.0	1.39	2.8	Late	79.6
Texas Blackhull kafir × feterita	————	Medium	72.0	1.06	2.8	Medium	80.4
Sumac	S. P. I. 35038	————	66.0	0.90	1.7	Late	80.7
Feterita*	F. C. 811	————	47.0	0.63	2.0	Late	80.8
Darso × Dwarf Yellow milo	————	Much	84.5	1.57	2.3	Late	81.7
Texas Blackhull kafir	F. C. 8962	————	51.5	1.18	1.1	Medium	81.8
Texas Blackhull kafir × darso	————	Medium	55.0	1.06	1.4	Medium	87.9
Darso	F. C. 6606	————	46.5	0.93	1.9	Medium	93.8
Texas Blackhull kafir × Day milo	————	None	43.0	0.96	1.6	Medium	106.7
Day milo	C. I. 480 × 332–187	————	25.0	0.84	2.0	Early	136.9
(Feterita × milo) × Dwarf Yellow milo	————	Much	88.0	1.25	4.3	Late	138.6
Feterita	C. I. 182	————	60.5	0.76	2.9	Early	148.7
Dwarf White milo	F. C. 8927	————	47.5	0.81	3.1	Medium	169.5
Dwarf White milo × Dwarf Yellow milo	————	None	47.0	0.97	3.2	Medium	182.3
Dwarf Yellow milo	C. I. 332	————	54.0	1.12	3.0	Medium	184.3
Feterita × milo	F. C. 8926	————	48.0	1.00	2.8	Medium	191.1
Feterita × (feterita × milo)	————	Medium	65.0	0.96	3.3	Early	204.1

*This variety germinated very poorly and produced very weak plants.

significant. When the average length of life of the female was correlated with the average number of eggs laid, the correlation coefficient was 0.686.

Characteristics of the sorghum hybrids and their parents that indicate relative vigor, *viz.*, height of plant, diameter of stalk, and number of tillers, are shown in Table 3. The number of eggs laid by females caged on the different strains did not appear to be correlated with hybrid vigor. Atlas sorgo×Dwarf Yellow milo, darso×Dwarf Yellow milo, Texas Blackhull kafir×Dwarf Yellow milo, and (feterita ×milo)×Dwarf Yellow milo showed extreme hybrid vigor. The first three of these hybrids can be classed as resistant and the last one susceptible, when the number of eggs laid is the criterion of resistance. Five of the hybrids, Texas Blackhull kafir×Sumac sorgo, Texas Blackhull kafir×(feterita×milo), Texas Blackhull kafir×feterita, Texas Blackhull kafir×darso, and feterita×(feterita×milo), were only slightly taller than either of their parents. Of this group the first four can be classed as resistant and the last one as very susceptible. Texas Blackhull kafir×Day milo was intermediate in height between its two parents. This hybrid appeared to be intermediate in resistance. Dwarf White milo×Dwarf Yellow milo was slightly shorter than either of its parents.

It appears from the data in Table 3 that fewer eggs were laid on late-maturing strains than on strains maturing early or intermediate. This probably is a mere coincidence, partly because two of the resistant parental varieties, *viz.*, Atlas and Sumac, are inherently late, and partly because in certain hybrids complementary factors for growth and late maturity, as well as complementary genetic factors for chinch bug resistance, were brought together. Time of maturity among varieties has shown no relation to chinch bug injury (3). Data on maturity are shown in Table 3, because late maturity is a common manifestation of hybrid vigor.

The method used and the results obtained in these experiments should serve as useful guides in breeding for increased resistance to chinch bug injury by indicating which hybrid combinations appear to carry cumulative factors for resistance and thus offer the greatest promise. The Texas Blackhull kafir×Sumac sorgo hybrid appeared to be more resistant than Atlas sorgo, one of the most resistant varieties of sorghum among the many that have been tested. This hybrid is being grown and selected with the hope of isolating homozygous strains that are more resistant than any variety now available.

SUMMARY

The determination of the inheritance of chinch bug resistance in sorghums by measuring the injury to the plants has been impossible because of the frequent occurrence of hybrid vigor in the plants, which enables them to escape serious injury. Chinch bugs confined on the stems of field-grown plants of susceptible sorghum varieties by means of small celluloid cages laid more eggs than those similarly confined on resistant varieties. Egg counts thus obtained offer a method for determining the genetics of resistance to chinch bug injury and for

indicating in the F_1 generation which crosses offer the greatest promise in breeding for resistance. When this criterion was used to measure chinch bug resistance, the data from 11 sorghum hybrids in the F_1 generation and their parents indicate that in most of the crosses resistance was dominant to susceptibility. The extent of hybrid vigor as measured by height of plant, diameter of stalk, and number of tillers did not appear to be definitely associated with chinch bug resistance as measured by oviposition and longevity of the females. In general, chinch bug females lived longer on the susceptible varieties, but the difference was small, and the duration of life is a poorer criterion for measuring chinch bug resistance than is the number of eggs laid.

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SATURATION DEGREE OF SOIL AND NUTRIENT DELIVERY TO THE CROP[1]

WM. A. ALBRECHT AND N. C. SMITH[2]

WITH the better understanding of the physico-chemical aspects of the clay fraction of the soil, the mysteries of the migration by the nutrient ions from the soil into the plant are rapidly submitting to solution. In fact, we now know that the reverse movement is possible, so that in fertility-depleted soils the nutrients may be going back to the soil to reduce the cation stock in the plant originally contributed by the seed. The colloidal phenomenon of exchange of cations is helping us to understand soil fertility more clearly. With more research attention to the anions, even these may let their behavior come within the pale of understanding. If the colloidal system in the plant root is opposed to the colloidal clay system with the not wholly invulnerable root membrane interposed, we may look to equilibrium of forces within and without as a helpful explanation. Should we reason on this simple physico-chemical basis, then the questions naturally arise whether soil fertility applications should be an attempt to provide but that needed for most economic service to the plant, or that for modification of the soil. It becomes a question whether applied nutrients should be used to saturate highly limited soil areas in the immediate root zone or to give low degree of saturation of the soil throughout the plowed layer of the common 2 million pounds.

This viewpoint prompted an experimental study of the degree of saturation of the soil by calcium as cation and by phosphate as anion as a factor in plant growth and in the movement of these ions from the soil into the crop as nutrient harvest.

PLAN OF EXPERIMENT

An extensive series of 2-gallon pots of surface soil of the Putnam silt loam was arranged to include treatments of one-fourth of the soil with calcium in amounts equivalent to that needed to saturate it completely; and but one-half that quantity. These same amounts of the calcium were also distributed through the entire soil. Additions of phosphate representing 100 pounds and 200 pounds of 38% phosphate per 2 million pounds of soil were applied in similar manner.

Thus, in the case of calcium, there were jars in which the upper fourth of the soils was completely saturated; some in which the deficit in calcium in this layer was remedied by but one-half; some in which only a light application was given to the entire soil body; and another in which it was given a heavier application. These latter two treatments amounted to roughly 600 and 1,200 pounds per 2 million pounds for a soil that had an initial pH of 5.6 and was originally only about half saturated with calcium. This soil was also low in soluble phosphorus and responds readily to such application by better crop yield. It gives, however, the best responses to lime alone, and to phosphates used in conjunction with lime. For purpose of convenience these treatments will be spoken of in the case of the

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 655. Received for publication January 6, 1940.

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limestone treatments as (a) partial saturation and (b) complete saturation; and in the case of phosphate treatments as (c) light dosage and heavy dosage in either case of treatment through the larger or the smaller soil volumes.

In mineral nature, this surface soil of the Putnam silt loam contains few, if any, "other than quartz" minerals which carry calcium. The subsoil is an impervious clay containing a high percentage of the beidellite clay colloid with an exchange capacity of more than 65 M.E. per 100 grams of clay. The surface soil used carried approximately 15% clay of which the exchange capacity combined with that of the organic matter gave it a total capacity of about 18 M.E. per 100 grams of surface soil.

Four crops were used in quintuplicate for each treatment. These included two grasses, bluegrass and redtop, and two legumes, sweet clover and Korean lespedeza. These selections were made in accordance with the generally accepted fertility demands by these crops, ranking those for bluegrass and sweet clover above those for redtop and Korean lespedeza.

The growths were harvested as forages at regular intervals to give five harvests of quintuplicate pots as carefully weighed amounts on constant moisture basis. Analyses were made for their contents of calcium and phosphorus to determine the fertility harvest for these nutrients applied in contrast to such from the untreated soil.

EXPERIMENTAL RESULTS

FORAGE HARVESTS

The single outstanding result throughout the experiment is the much larger yields of forage and fertility harvest that resulted when the treatments were applied to only the smaller portion of the soil to give it the higher degree of saturation by the ion of the treatment. The increases in forage yields as percentage over the untreated soil are assembled in Table 1. Comparison of the second column of figures with the first under each separate crop shows the much larger percentage increases where the treatment was put into the smaller soil volume.

TABLE 1.—*Increases (percentage) in forage harvests from limestone and phosphate distributed through large and small soil volumes.*

Soil treatment		Grasses				Legumes			
		Redtop		Bluegrass		Lespedeza		Sweet clover	
Kind	Magnitude	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.
Limestone	Partial saturation	15.5	15.5	−3.8	9.7	4.8	13.7	25.1	50.1
	Complete saturation	1.0	36.0	0.0	33.0	2.5	28.0	23.2	89.1
Phosphate	Light dose	8.8	4.3	9.0	34.4	20.0	23.0	22.8	51.0
	Heavy dose	14.3	12.3	15.7	18.0	21.4	22.4	27.2	70.8

In the case of limestone this increase held for the nonlegumes as well as for the legumes. In fact the figures for the former were generally larger than those for Korean lespedeza, though not as large as those for sweet clover. The yields show clearly that, as measured by forage increases, the higher degree of saturation by calcium in a limited soil area was more effective than a moderate or less degree of saturation in a larger soil area. This raises the question, and answers it forcefully, whether the economical use of lime is not one of feeding the plant calcium more than one of neutralizing the entire soil area of the root zone.

Phosphate, like the calcium carbonate, also showed more influence on the crop yield when the treatment was concentrated into a part of the soil, though this illustration was not as pronounced, in general, as that of the effects by the limestone. In the case of sweet clover, the effects by phosphates were almost equivalent to those by limestone in terms of percentage yield increase. For both the single soil treatments of calcium and phosphate additions in general, the crop yield increases were larger as the treatment was used to give a higher degree of soil saturation.

FERTILITY HARVEST OF CALCIUM

Analyses of the crops for calcium when lime was applied show that the crop content of this plant nutrient as totals per acre responded with larger differences in the increases than was the case for the forage yields. The higher degree of soil saturation by the application of the calcium into a limited soil area gave increases as much as 2½ times as large as where this same amount was distributed through more soil. This is demonstrated clearly in Table 2. Again, the nonlegumes demonstrated increases in calcium harvested from the soil which were

TABLE 2.—*Increases (percentages) in calcium and phosphorus harvests from limestone and phosphate distributed through large and small soil volumes.*

Soil treatment		Grasses				Legumes			
		Redtop		Bluegrass		Lespedeza		Sweet clover	
Kind	Magnitude	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.
		Calcium Harvest							
Limestone	Partial saturation	19.5	45.0	16.2	58.6	12.6	27.7	34.2	59.5
	Complete saturation	37.7	87.5	48.7	129.0	21.0	43.9	46.0	94.0
		Phosphorus Harvest							
Phosphate	Light dose	31.0	6.0	27.3	70.0	41.3	41.3	28.0	94.0
	Heavy dose	16.0	23.4	43.6	34.4	39.1	46.7	29.6	130.0

even greater than the increases taken by the legumes. Redtop was superior in this respect to Korean lespedeza, and bluegrass to sweet clover. It suggests that because these crops manage to produce vegetation on soils low in lime, we have perhaps not been giving sufficient attention to the capacity of the grasses to take lime for their possible improved feeding value.

FERTILITY HARVEST OF PHOSPHORUS

The total phosphorus harvested in the crops where the soils were given phosphates shows greater increases when the treatment was concentrated into the lesser amounts of soil for all but two of the eight cases as given in Table 2. Redtop and Korean lespedeza with the lower phosphate applications failed to give greater increases where the phosphate was applied in the surface soil only. In the other cases the differences were very significant and larger than any others in the case of sweet clover. In terms of forage, of calcium harvest, and of phosphorus harvest through the crop, this last crop showed the outstanding response to both calcium and lime applications into the limited soil area.

The crop responses rank these crops in the order as they are commonly arranged in fertility requirements. The bluegrass and the sweet clover showed greater response to the soil treatments than was true for the other two. They also removed larger amounts of calcium and phosphorus from the soil.

FERTILITY HARVEST OF NITROGEN

Since both nonlegumes and legumes were included, the significance of concentrating the calcium and phosphates into less soil as these influence nitrogen fixation by legumes and nitrogen removal from the soil can be measured. The data assembled into Table 3 are in agreement, in principle, with those previously given. The increases in

TABLE 3.—*Increases (percentages) in nitrogen harvests from limestone and phosphate distributed through large and small soil volumes.*

Soil treatment		Grasses				Legumes			
		Redtop		Bluegrass		Lespedeza		Sweet clover	
Kind	Magnitude	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.
Limestone	Partial saturation	-26.4	15.0	-18.5	14.3	20.0	30.6	39.8	67.3
	Complete saturation	-13.0	23.1	-4.5	40.8	13.0	52.4	35.4	113.7
Phosphate	Light dose	-12.8	-6.2	-15.5	25.0	47.3	54.0	25.9	65.1
	Heavy dose	-10.0	-10.0	-5.8	0	50.5	41.8	34.1	80.8

nitrogen harvested were much greater again where these soil treatments were used so as to provide them at higher degrees of soil saturation. Even for nonlegumes the higher concentration within the soil of the same application of limestone was much more effective in delivery of nitrogen from the supply in the soil to the crop. Small dosages or lower degree of saturation gave negative increases or amounts in the crop below that in crops on unlimed soil. This suggests that the introduction of limestone encouraged microbiological competition sufficient to utilize the effect by the calcium to the detriment of the crop competing for the supply of nutrients even other than calcium. Similar situations were provoked by the addition of the phosphatic fertilizers for the nonlegumes.

In the case of the legumes, the treatments all increased crop yields. The Korean lespedeza, however, was not correspondingly responsive to the higher applications of phosphate into the smaller soil volume. The sweet clover gives distinct evidence of the influence by both the calcium and the phosphate on the nitrogen increase by this crop, but especially of the effects when these treatments are concentrated into small soil volumes to give them higher degrees of nutrient ion saturation. Thus in this crop the higher nitrogen harvest, probably much through nitrogen fixation, agrees with the higher fertility delivery as calcium and phosphorus by the soil to the plant.

DISCUSSION AND SUMMARY

The data all emphasize the fact that more nutrients were delivered by the crops because of the higher degree of the soil saturation even of only a limited part of the soil. This area of soil was seemingly large enough to prohibit injury through excessive salt concentrations. These increased movements of the nutrients into the crops were roughly paralleled by increases in forage yields, though not directly so. Thus, there has resulted in most cases increased concentration of nutrients within the crops to give them higher forage feed value. Thus, the efficiency of the treated soils in terms of tonnage yield per unit of nutrient delivered is lower than the efficiency of the untreated soils, but it may be far more efficient in producing an animal feed of higher calcium, phosphorus, and protein concentrations. The increased use of nitrogen by the crop points to the significance of calcium and phosphorus in making this phase of plant metabolism operate effectively in case of the nonlegumes as well as for legumes.

Since calcium and phosphorus are the two most significant soil needs in the corn belt, as shown by past agronomic experience, by soil development, and by crops in their ecological array, we may well look forward to their wider use. For more effectiveness in practice, however, limestone and phosphate should be applied in more limited soil areas rather than distributed through the soil zone. Possibly not only the concentration within limited soil zones should deserve consideration, but also some efforts toward retardation of their rate of adsorption for reaction with the soil. Effectiveness of granular forms of such soil treatments may be premised on the greater efficiency of the nutrients when in areas of higher degrees of saturation. Efforts to

improve applications for such effectiveness should give results in terms of crop increases.

Since the very acid clay is active even to the point of removing calcium from the mineral lattice[3] and since a calcium clay is not so active in the removal of bases from plant roots,[4] perhaps the higher degree of calcium saturation in limited soil areas lessens the activity by the soil in adsorbing the anion phosphorus. If this is the case, then the applied phosphorus remains longer in the soil without reacting with it and may explain, in part, the greater efficiency of phosphates when used on limed soils[5] or those liberally stocked with calcium.

These results suggest most forcefully that in liming and fertilizing the soil, attention must go to the degree of saturation of the soil. The use of such soil treatments will be more effective when applied in limited soil areas to feed the plant than when applied through greater areas to modify the soil condition.

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[3]GRAHAM, ELLIS R. Primary minerals of the silt fractions as contributors to the exchangeable base level of acid soils. Soil Science (In press).

[4]JENNY, HANS, and OVERSTREET, R. Cation interchange between plant roots and soil colloids. Soil Sci., 47:257–272. 1939.

[5]ALBRECHT, WM. A. and KLEMME, A. W. Limestone mobilizes phosphates into Korean lespedeza. Jour Amer. Soc. Agron., 31:284-286. 1939.

NOTES

SPACING OF CORN USED AS GREEN MANURE

IN PLANNING an experiment in which corn was to be grown as a green manure crop the question arose as to how thick it should be seeded and what would be the effect of close spacing of the plants on their nitrogen content. Various reports in the literature on rate of planting show that the tonnage of stover increases with close spacing beyond the point where the yields of grain decline. No data were found, however, to show what rate would give the largest tonnage of dry matter irrespective of the grain yield. Preliminary tests were made in 1932 at the Experiment Station Farm at Wooster, one on Canfield silt loam, the other on nearby Chippewa loam. Inquiries regarding the results have indicated enough interest to justify this brief report.

Blue Ridge, a variety with too long a season to mature grain in northern Ohio, was planted by hand in duplicated plots 18 feet square at the spacings indicated in Table 1. Ten representative plants from each plot were cut close to the soil in late September, weighed at once, and taken to the laboratory where they were thoroughly chopped and minced, ears included, and small aliquots taken for the determinations of dry matter and nitrogen. The data given in Table 1 are averages of the duplicate plots.

TABLE 1.—*Dry matter and nitrogen content of Blue Ridge corn plants at close spacing.*

Spacing of plants, inches	Plants per acre (calculated)	Yield of dry matter		Nitrogen content	
		Per plant, grams	Per acre, lbs.	Of dry matter, %	Per acre, lbs.
On Canfield Silt Loam, Planted May 24, Sampled Sept. 25, 1932					
32×12	16,335	172.2	6,203	0.99	61.4
24×12	21,780	128.9	6,190	0.98	60.7
16×12	32,670	123.6	8,900	0.77	68.5
12×12	43,560	115.0	11,044	0.59	65.2
8×12	65,340	80.9	11,655	0.58	67.6
On Chippewa Loam, Planted May 24, Sampled Sept. 20, 1932					
32×12	16,335	347.2	12,505	0.760	94.9
24×12	21,780	261.5	12,557	0.765	96.1
16×12	32,670	199.7	14,383	0.700	100.7
12×12	43,560	145.5	13,974	0.625	87.3
8×12	65,340	106.3	15,310	0.585	89.6

The data calculated to an acre basis show that the closer spacing resulted in a larger production of total dry matter, a decline in the percentage of nitrogen in the dry matter, and a fairly constant nitrogen content per acre. The uniformity of the nitrogen content per acre suggests that nitrogen was a limiting factor, and that the plants spaced 32×12 inches were able to use the available nitrogen as effectively as the closer spaced plants. In comparing the data from

the two soils, the more fertile Chippewa soil produced distinctly larger amounts of dry matter, but the percentage of nitrogen was no higher than on the Canfield soil.

Corn grown for ensilage in Ohio, in rows 42 inches apart, harvested in September, usually analyzes about 1% of nitrogen on a dry matter basis. At the closer spacing of this test, or when seeded with a grain drill in subsequent tests, the corn, sampled in September, has been characterized by a nitrogen content of only 0.6% of the dry matter.

A crop with such a low nitrogen content ordinarily would not be considered suitable for green manure purposes. It is being used experimentally on heavy soils with the aim of incorporating sufficient bulk of coarse organic matter to improve the drainage and aeration of the plowed horizon. With potatoes as the test crop, any procedure which improves the aeration has proved beneficial.[1] The anticipated nitrogen deficiency arising from the presence of the corn residue in the soil has been corrected by a moderate increase in the proportion of nitrogen in the potato fertilizer.—JOHN BUSHNELL, *Ohio Agricultural Experiment Station, Wooster, Ohio.*

AN INEXPENSIVE PHOTO-ELECTRIC COLORIMETER FOR PHOSPHORUS DETERMINATION

TO increase the sensitivity of the colorimetric quick test for available phosphorus in soil, the apparatus illustrated here was built. A standard beam of light is projected through a fixed quantity of the blue solution in a standard flat-sided, glass jar and on to the lens of a photographer's photo-electric exposure meter. By using for comparison solutions of known phosphorus content the dial of the meter can

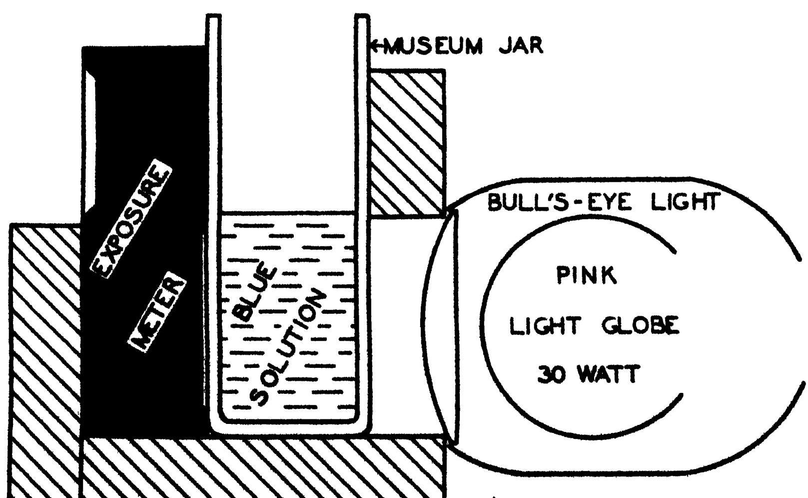

FIG. 1.—Inexpensive photo-electric colorimeter for phosphorus.

[1]BUSHNELL, JOHN. Sensitivity of the potato plant to soil aeration. Jour. Amer. Soc. Agron., 27:251–253. 1935.

be calibrated to read directly in parts of available phosphorus per million parts of soil. This apparatus seems to be both more sensitive and more accurate than matching colors by eye.

The construction of the apparatus is easily seen from the diagram (Fig. 1). For routine analysis an ordinary 30 watt pink (for contrasting wave lengths) electric light globe in a cheap bull's-eye spot light seems to be a satisfactory source of light. A check with distilled water will show if there is any variation in intensity. A rectangular glass museum jar of 150 ml. capacity makes a satisfactory container for the blue solution. A box to hold the parts in position may be made of wood with an opening at the front for the light, at the rear for reading the dial of the meter, and at the top for inserting the meter and jar.

Experience shows that different exposure meters of the same make and model may differ very widely in their reading, but each meter seems to be quite constant in itself, and the calibration of each meter may be used with confidence for some time.—D. W. PITTMAN and R. PARRY, *Agricultural Experiment Station, Logan, Utah.*

SMALL GRAIN BUNDLE TIER

IN a previous article[1] a machine for tying rod-row bundles of the small grains was described. During the intervening years it has become apparent that a larger and more flexible piece of equipment would be desirable—a machine that would use a heavier twine, tie bundles tighter, tie several bundles together, and be power driven.

During the past harvest season the assembly described herein was used and proved highly successful. It tied single bundles tightly enough so that slippage was negligible and from two to five bundles were tied together without difficulty. The speed and operation of the machine was only limited by the operator's ability to supply it with bundles. Common binder twine was used and twine cost was reduced to a minimum because the machine uses the minimum length of twine when making a band.

The machine (Fig. 1) was made by mounting the binding mechanism of the smallest new Light Running John Deere binder together with a small gasoline engine on an old Ford chassis. The jackshaft mounted between the engine and the binder was necessary to reduce the engine speed and change from belt to chain drive. No clutch other than that built into the binding mechanism is included on our machine, but it would be convenient to have one in the jack-shaft assembly. In both figures the needle is shown protruding above the table, but in the neutral position it is completely below it.

A close-up of the working table and tying mechanism is shown in Fig. 2. The original needle guide and straw guard were removed and replaced by the iron straps and sheet metal shown in the picture. Also, the knife holder of the knotter assembly was removed and shortened so as to allow the bundle to come closer to the knotter bills and be tied more tightly. The original equipment gave a very loose tie on small bundles.

[1]Jour. Amer. Soc. Agron., 28:395–403. 1936.

An important item of the assembly which is not clearly seen in either picture is a long rubber band (a light spring would function as well) which serves as a tension on the twine. The band is attached

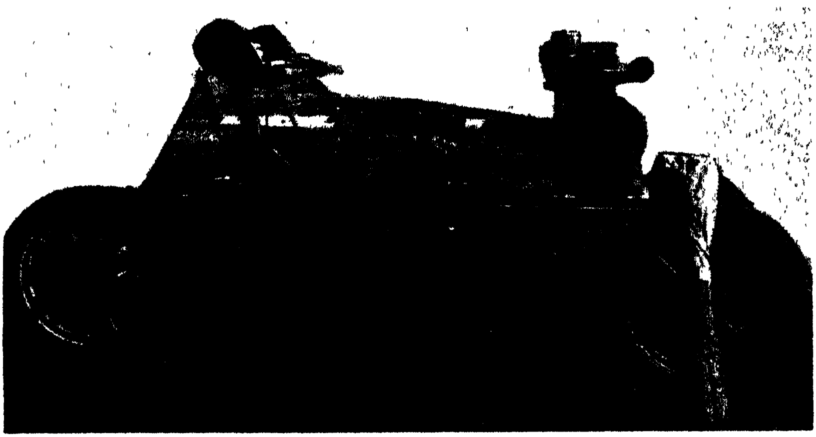

FIG. 1—The binding machine.

FIG. 2.—Working table and tying mechanism.

to a metal eye which is slipped over the twine between the gear tension of the original equipment and the point where the twine enters the needle. This is necessary to make the needle follow up the twine and take up slack and is the secret to tying small bundles tightly.

The tying mechanism is actuated by a slight tap of the hand on the trip-lever which in turn engages the clutch of the drive assembly. A small rubber band prevents the trip chain from becoming tangled. If the trip lever fails to return to the neutral position, the tying mechanism continues to run.

The bundles, ready for tying, are passed to the operator from the left. He presses the bundle against the twine until it is directly under the knotter and then presses the trip lever. The needle comes up from the left carrying the twine on around the bundle and into the knotter. As the tie is made, the operator gives the bundle a quick downward jerk which removes the tie from the knotter bills. The tied bundle comes free below the twine, the same as in any binder. One operator can tie bundles with two bands as fast as two helpers can roll the sacks properly for tying and hand the bundles to him.

In the ground driven binder, the packer shaft, which is the drive member for the binding head, makes 171 r.p.m. at 2½ miles per hour and the needle shaft makes 57 r.p.m. The machine we are using runs the needle shaft at 15 r.p.m., a very satisfactory speed.

Any good mechanic should be able to make a satisfactory assembly similar to the one herein described.—JAMES W. THAYER, JR., and HUBERT M. BROWN, *Michigan State College, East Lansing, Mich.*

EFFECTS OF INBREEDING LITTLE BLUESTEM[1]

IN a recent paper,[2] the writer indicated that in little bluestem (*Andropogon scoparius*) there appeared to be considerably less reduction in vigor following inbreeding than occurred in big bluestem (*A. furcatus*). The inbred plants reported at that time showed no significant decrease in size as compared to the open-pollinated lines. This test included approximately 50 plants in their first inbred generation. Later tests with other lines of little bluestem have shown that, while the vigor of certain lines is only slightly if at all affected by inbreeding, there are lines which give rather marked losses of

FIG. 1.—Little bluestem (*Andropogon scoparius*). A line showing marked reduction of vigor following inbreeding. The row on the left is the selfed progeny and the one on the right the open-pollinated progeny of an S_1 plant.

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[1]Contribution No. 300, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan.

[2]ANDERSON, KLING L., and ALDOUS, A. E. Improvement of *Andropogon scoparius* Michx. by breeding and selection. Jour. Amer. Soc. Agron., 39:862–869. 1938.

vigor even in the first inbred generation. Variations appeared in the response of the various plant lines studied, however, and observational data indicated that little bluestem generally shows smaller reduction in vigor from inbreeding than does big bluestem.

In Fig. 1 are shown two rows of progeny of a plant in its first inbred generation, the left row from selfed and the right from open-pollinated seed of this plant. The inbred row, now in the S_2 generation, shows considerable reduction in vigor as compared to the inbred row shown in Fig. 2.

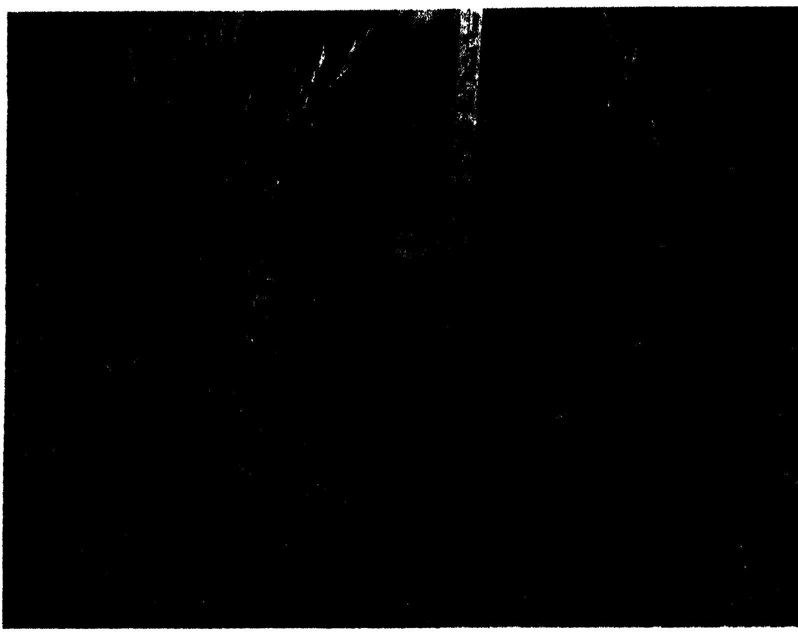

FIG. 2.—Little bluestem (*Andropogon scoparius*). A line in which inbreeding has no marked effect in reducing vigor. Both rows shown are the progeny of the same S_2 plant, the left hand row having been grown from open-pollinated seed and the right hand row from seed that was selfed.

The illustration in Fig. 2 is a photograph of two progeny rows from a plant in its second inbred generation, the row on the right having been grown from selfed and the row on the left from open-pollinated seed of this plant. This line, even in the S_3 generation shows a great deal smaller reduction in vigor than does the line shown in Fig. 1 in its S_2. The inbred is somewhat less leafy than the open-pollinated row from the same mother plant, but it has grown to the same height and has seeded normally.—KLING L. ANDERSON, *Kansas Agricultural Experiment Station, Manhattan, Kan.*

BOOK REVIEW

PLANT PHYSIOLOGY

By Bernard S. Meyer and Donald B. Anderson, New York: D. Van Nostrand Co. X+696 pages, illus. 1939. $4.50.

TO the growing list of excellent publications upon plant physiology must be added this one. It has been developed from the courses in plant physiology taught at the Ohio State University and the University of North Carolina by the authors. The attempt to "bring into bold relief the fundamental principles of plant physiology rather than to present only an encyclopedic compilation of undigested and sometimes contradictory facts" seems to have been measurably successful. Further, material from the supporting basic sciences has been injected in sufficient amount to make the book a complete unit in itself. The discussions of material from physics and chemistry are well presented, and the introduction of drawings and discussion on structure of organs, tissues, and cells is particularly welcome and helpful. The material is presented in 37 chapters, in turn well organized and subdivided into paragraphs with bold face headings. At the end of various chapters are lists of discussion questions, suggestions for collateral reading, and a selected bibliography. A subject and an author index complete the book It is well printed with good-sized type and adequate spacing between lines to make for easy reading. (H.B.T.)

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Richard Bradfield

RESEARCH MONOGRAPHS

PRESIDENT ALWAY has appointed a special committee of the Society to deal with the matter of research monographs as discussed at the recent meeting of the Association of Land Grant Colleges and Universities. Doctor Richard Bradfield has been named Chairman of the Committee, with M. A. McCall and J. D. Luckett as the other members.

The chief function of this special committee is to represent the Society in dealing with a committee representing the Association of Land Grant Colleges and Universities. At this time Doctor Bradfield and his committee would welcome suggestions from members of the American Society of Agronomy as to fields in which there is the greatest need for the proposed reviews, outstanding authorities who might be asked to prepare the monographs, and practicable means of publication.

In order to make possible a better understanding of the whole matter there is reproduced herewith the report of the committee of the Association of Land Grant Colleges and Universities as presented to the Association at its meeting in Washington, D. C., on November 14, 1939.

REPORT OF THE COMMITTEE ON RESEARCH MONOGRAPHS

At the 1938 meeting of the Association of Land Grant Colleges and Universities, the Joint Committee on Projects and Correlation of Research stressed the need of "monographs which will assemble, organize, condense, and evaluate available information on the more important subjects of agricultural research" so that new researches may be planned on the basis of a comprehensive knowledge of previous work. The committee recommended that the Office of Experiment Stations in the U. S. Dept. of Agriculture be requested to establish such a service; and that a committee of five be appointed "to determine the timely problems on which monographs should be prepared, and to advise with the Office of Experiment Stations in making plans for preparing and publishing the same." It was suggested that two members of this committee be appointed from the U. S. Dept. of Agriculture, two from the state experiment stations, and one from the National Research Council. These recommendations were approved by the Executive Body and the Executive Committee of the Association.

The committee has made a canvass of the U. S. Dept. of Agriculture and the state experiment stations as to subjects that are most in need of monographic treatment. The replies reveal widespread interest in the proposal, and the urgent need of the early preparation of certain monographs, as an aid in planning new research. Several hundred subjects have been suggested. Among those which appear to be of greatest interest are the following:

Effects of temperature and light on the growth and reproduction of plants.

Value of "trace elements" in animal and plant nutrition.

Role of minerals and of vitamins in animal nutrition.

Ensiling grasses and legumes.

Nutritive value of pasture grasses as influenced by soils, climate, and fertilizer treatments.

Nature of disease resistance in plants and animals.

Physiology and biochemistry of fungi.

Relation of soil organic matter to soil erosion.

Nature of soil colloids.

It is the opinion of the committee that the monographs should be on subjects that require fundamental research and that are of widespread interest. Before any monograph is undertaken the counsel and cooperation of interested agencies should be sought. To this end the committee proposes to supplement the data already gathered by requesting each of the national scientific societies which has a definite relation to agriculture to express its judgment on three points—subjects in its field that are in greatest need of such review, outstanding authorities who might be invited to prepare the monographs, and practicable means of publication.

The committee is of the opinion that the type of monograph which will be most serviceable is one which will review and appraise recent developments, having in mind primarily the needs of modern research, rather than one which is mainly historical.

The Committee on Projects and Correlation of Research suggested that the necessary funds might be provided by Congressional appropriation or by contributions from interested agencies. It is the judgment of this committee that it would not be practicable at this time to seek Congressional appropriations, but that the monographs be made possible through the cooperation of interested agencies such as the U. S. Dept. of Agriculture, the state agricultural experiment stations, scientific journals, commercial publishing houses, and by the sale of the monographs.

The committee recommends further that the monographs do not appear as a separate series, but in any existing channel of publication which may be most expedient, in each case, such as books that are printed and sold by publishing houses, publications of the U. S. Dept. of Agriculture and the state agricultural experiment stations, and scientific journals. The function of this committee, therefore, would be to cooperate with the Office of Experiment Stations in promoting and authorizing the monographs—not to publish them.

E. J. Kraus, National Research Council
C. B. Hutchison, California
O. E. Reed, U.S.D.A.
P. V. Cardon, U.S.D.A.
S. W. Fletcher, Pennsylvania.

SUMMER MEETING OF NORTHEASTERN SECTION

ANNOUNCEMENT has been made by Ralph W. Donaldson, secretary-treasurer of the Northeastern Section of the Society, that the 1940 summer meeting of the Section will be held at Pennsylvania State College July 11 and 12. During the meeting there will be an opportunity to visit the Pasture Research Laboratory located at State College. It is also stated that the ladies are included in the invitation.

NEWS ITEMS

JACOB ELRY METZGER, Director of the Maryland Agricultural Experiment Station and head of the Department of Agronomy of the University of Maryland, died December 25, 1939, at Lake Worth,

Florida, where he had gone for a vacation and rest. Director Metzger was long a member of the American Society of Agronomy.

THE BAYER-SEMESAN COMPANY announces the following educational one-reel, sound-on-film motion pictures: "Black Scourge", "Feeding the Multitude", "Grain Thieves", "Seeds of Prosperity", "Peruvian Gold", "Tall Corn", "King Cotton", and a film of last year's national corn husking contest. For further information about the free use of these films, which are available both in standard 35 mm and 16 mm size, may be obtained by addressing Mr. J. Hunter Gooding, Jr., Bayer-Semesan Company, Wilmington, Delaware.

KARL MANKE, who for the past thre eyears has been in charge of the sweet clover breeding program at the Nebraska Agricultural Experiment Station under the direction of E. A. Hollowell, has accepted a position at the Texas Agricultural Experiment Station where he will continue the same line of research.

REPRESENTATIVES of the American Society of Agronomy and of the Soil Science Society of America have been designated for each of the states and the District of Columbia for the purpose of securing new members for the two societies and to act as correspondents for this JOURNAL. The list will be published in an early number of the JOURNAL.

ERRATUM

ATTENTION is called to the fact that the Rex barley described in the report on barley registration appearing in the January 1940 number of the JOURNAL (page 84) is a *two-rowed* barley; not six-rowed as stated in the published description.

JOURNAL
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VOL. 32 MARCH, 1940 NO. 3

EFFECT OF "CLIPPING" OR RUBBING THE OAT GRAIN ON THE WEIGHT AND VIABILITY OF THE SEED[1]

G. H. CUTLER[2]

THE practice of clipping oat grains by mechanical means has been employed for many years. Its chief purpose is to increase the test weight, though it also helps to improve the appearance of the sample. Seedsmen and exhibitors at grain shows find that rubbing or clipping works very beneficial changes on oats. Even mediocre looking oats can be greatly improved in both test weight and general appearance by this so-called "face-lifting" process.

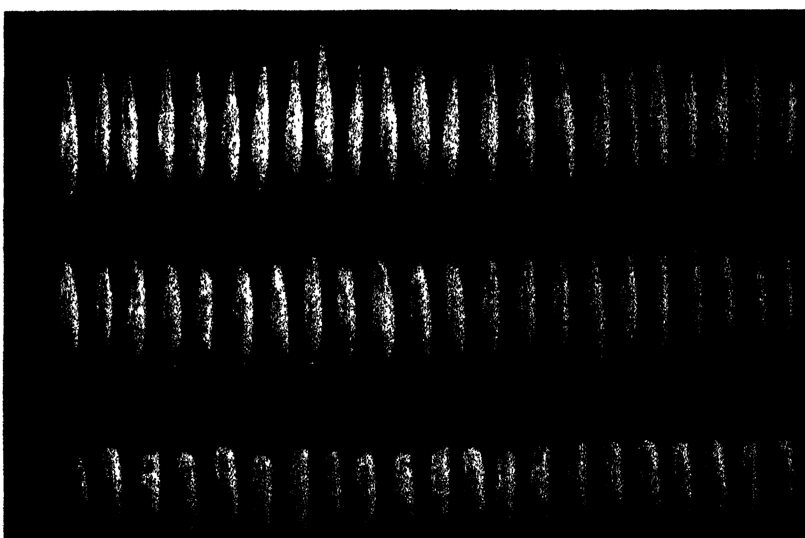

FIG. 1.—Representative grains of Cartier variety, showing treatment. Top row, no treatment (original); middle row, lightly rubbed; bottom row, heavily rubbed. 1.7 times natural size.

[1]Contribution from Dept. of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Ind. Also presented at the annual meeting of the Society held in New Orleans, La., November 22, 1939. Received for publication November 18, 1939.

[2]Assistant Chief and Professor of Agronomy.

Clipping, as is well known, consists in removing the tips or tails and awns from the hulls, as well as polishing and cleaning the grain so that all extraneous materials are removed. Some varieties of oats have more hull extending beyond the end of the meat or caryopsis than others. This, together with awns and other materials that may be attached to the exterior of the hull when removed, permits the oat grains to lie more closely together in a more compact and solid mass.

From the standpoint of the seed producer, the exhibitor, and even the feeder, clipping seems desirable. Whether it is fraught with detrimental effects to the seed, however, may be open to question. The purpose of this study was to ascertain the effect, if any, of clipping oats upon the viability or germinability of the seed.

It is generally agreed among agronomists that dehulled oats, when used as seed, are inferior to oats with hulls. Anderson[3] states that shelled (dehulled) oats were considerably inferior to unshelled oats, not only as regards viability and germinative energy but also in yield. He found that yield was reduced 20 to 25% in the case of the shelled oats. Bayles and Coffman[4] observed that dehulling oats reduced the germination 5.8% (field tests) and that as high as 6.3% of the plants failed to reach maturity.

It might be assumed, therefore, with some degree of logic that clipping the oat hull so closely as to expose the caryopsis might result in expediting the rate at which its viability is lost. Published data based on experimental tests are very meager on this point.

TABLE 1.—*The effect of rubbing oat grains of six varieties* of oats on the test weight, 1935 harvest crop.*

Varieties	Test weight				
	No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight	
				Lbs.	%
Alaska	33.3	39.6	43.4	10.1	30.3
Cartier	30.0	36.4	40.5	10.5	35.0
Minota	22.5	28.4	32.8	10.3	45.7
Columbia	32.8	37.7	42.9	10.1	30.7
Markton × Idamine (C. I. No. 2570)	27.2	33.5	37.4	10.2	37.5
Gopher A	25.1	31.9	35.2	10.1	40.2
Gopher B	23.7	30.7	33.9	10.2	43.0
Average	27.8	34.0	38.0	10.2	37.4

*Seven samples.

[3]ANDERSON, J. A. On the viability of shelled oats. Landmannen, 13, No. 42: 676–678. 1902.

[4]BAYLES, B. B., and COFFMAN, F. A. Effects of dehulling seed and date of seeding on germination and smut infection in oats. Jour. Amer. Soc. Agron., 21: 41–51. 1929.

TABLE 2.—*The effect of rubbing oat grains of six varieties* of oats on the test weight, 1936 harvest crop.*

Varieties	Test weight				
	No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight	
				Lbs.	%
Alaska	38.2	42.2	45.0	6.8	17.8
Cartier	37.5	41.0	43.6	6.1	16.2
Minota	26.1	30.3	34.4	8.3	31.8
Columbia	36.5	40.6	44.3	7.8	21.3
Markton × Idamine (C. I. No. 2570)	32.9	37.7	40.8	7.9	24.1
Gopher A	35.1	37.9	41.8	6.7	19.1
Gopher B	32.3	36.4	39.7	7.4	22.9
Average	34.0	38.0	41.3	7.3	21.8

*Seven samples.

TABLE 3.—*The effect of rubbing oat grains of six varieties* of oats on the test weight, 1937 harvest crop.*

Varieties	Test weight				
	No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight	
				Lbs.	%
Alaska	34.1	40.5	42.4	8.3	24.4
Cartier	33.3	37.6	40.2	6.9	20.7
Minota	26.4	33.1	36.4	10.0	37.7
Columbia	31.2	37.9	41.4	10.2	32.6
Markton × Idamine (C. I. No. 2570)	28.5	35.6	39.5	11.0	38.5
Gopher A	30.8	36.0	38.6	7.8	25.3
Gopher B	31.4	36.4	39.1	7.7	24.5
Average	30.8	36.9	39.6	8.8	29.1

*Seven samples.

TABLE 4.—*Averages of six varieties* for 3 years 1935, 1936, and 1937.*

Years	Test weight				
	No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight	
				Lbs.	%
1935	27.8	34.0	38.0	10.2	37.4
1936	34.0	38.0	41.3	7.3	21.8
1937	30.8	36.7	39.6	8.8	29.1
Average	30.9	36.3	39.7	8.8	29.4

*Seven samples.

MATERIALS AND METHODS

The varieties studied in these tests include Alaska, Markton×Idamine (C. I. No. 2570), Cartier, Minota, Columbia, and Gopher. The last four are grown very extensively in Indiana. Two samples of Gopher were used. Gopher A was in good condition when clipped and stored, while Gopher B was musty when clipped and stored.

The technic of clipping consisted in rubbing or kneading about 3 pounds of seed at a time in a muslin sack that was about three parts filled. The sack of grain was grasped with both hands and vigorously kneaded and pressed against the surface of a heavy table. After treating the sample in this manner for a short time, it was passed through a strong current of air to remove the light chaffy materials. It was then divided with the Boerner sampler into two parts, one of which was retained and designated "lightly rubbed", while the other was again vigorously rubbed to improve further its appearance and test weight. The second rubbing treatment was sufficiently vigorous and effective to break away the hull at the end distal to the embryo and to expose the end of the meat or caryopsis. Even in some instances, the hull was split and the entire length of the caryopsis was exposed. This sample was again passed through a strong current of air to remove chaffy materials and designated "heavily rubbed" (Fig. 1).

TABLE 5.—*Germination tests of untreated (original), lightly rubbed, and heavily rubbed seed of six varieties* of oats grown in 1935 and stored 4, 16, and 40 months, respectively.*

Variety	Treatment	Percentage germination			
		Dec., 1935	Apr., 1936	Apr., 1937	Apr., 1939
Alaska	No treatment (original)	95.0	93.5	93.0	95.0
	Lightly rubbed	96.0	92.5	93.5	97.0
	Heavily rubbed	95.5	94.0	94.5	97.0
Cartier	No treatment (original)	93.5	92.5	93.0	95.5
	Lightly rubbed	94.5	94.0	91.5	95.0
	Heavily rubbed	93.0	93.0	92.0	96.5
Minota	No treatment (original)	93.0	93.5	93.0	94.0
	Lightly rubbed	95.0	92.5	95.0	94.5
	Heavily rubbed	93.0	92.0	95.0	94.5
Columbia	No treatment (original)	97.5	94.5	94.5	95.5
	Lightly rubbed	96.5	93.0	95.0	96.0
	Heavily rubbed	94.0	95.5	96.5	95.5
Markton × Idamine (C. I. No. 2570)	No treatment (original)	96.5	93.0	92.0	93.5
	Lightly rubbed	96.5	92.0	94.0	94.5
	Heavily rubbed	94.5	90.0	93.0	94.0
Gopher A	No treatment (original)	93.0	93.5	87.0	84.0
	Lightly rubbed	94.5	93.0	83.5	85.0
	Heavily rubbed	95.0	90.0	88.5	85.0
Gopher B†	No treatment (original)	89.0	89.0	75.5	70.0
	Lightly rubbed	91.0	85.5	78.5	70.5
	Heavily rubbed	86.5	84.5	78.0	72.5

*Seven samples.
†Sample slightly musty when rubbed and stored.

Before being placed in storage, tests for test weight were completed using the standard equipment for this purpose. The samples were then stored in a heated room in a galvanized container which was equipped with a close-fitting lid.

The germination tests were made in a Minnesota germinator in accordance with the official method recommended by the U. S. Dept. of Agriculture. A limited number of germination tests were also made in soil in the greenhouse.

EXPERIMENTAL RESULTS

EFFECT OF RUBBING THE OAT GRAIN ON THE TEST WEIGHT

The effect of rubbing oat grains on the test weight is shown in Tables 1, 2, 3, and 4 for the seed from crops harvested in 1935, 1936, and 1937, respectively.

The above data reveal that rubbing oat seed vigorously, followed by fanning, greatly increases the test weight. This was the case with all varieties and in all three seasons during which these tests were made. It is of interest to note that the lighter weighing oats were benefited relatively more than the heavier weighing samples. The Minota variety represents the light weighing variety while the Cartier and Alaska are among the heavy weighing varieties. The

TABLE 6.—*Germination tests of untreated (original), lightly rubbed, and heavily rubbed seed of six varieties* of oats grown in 1936 and stored 4 and 28 months, respectively.*

Variety	Treatment	Percentage germination		
		Dec., 1936	Apr., 1937	Apr., 1939
Alaska	No treatment (original)	96.5	96.5	94.5
	Lightly rubbed	97.0	97.5	97.0
	Heavily rubbed	97.5	96.0	97.5
Cartier	No treatment (original)	96.0	94.0	97.0
	Lightly rubbed	97.0	96.5	95.0
	Heavily rubbed	96.0	96.5	96.0
Minota	No treatment (original)	92.5	92.5	93.5
	Lightly rubbed	92.5	93.0	94.5
	Heavily rubbed	94.5	95.5	96.0
Columbia	No treatment (original)	97.5	97.5	97.0
	Lightly rubbed	96.5	95.5	97.0
	Heavily rubbed	97.0	97.0	97.0
Markton × Idamine (C. I. No. 2570)	No treatment (original)	93.0	96.5	93.5
	Lightly rubbed	93.5	95.5	93.5
	Heavily rubbed	93.0	95.5	95.5
Gopher A	No treatment (original)	95.5	93.5	96.5
	Lightly rubbed	95.0	95.0	95.5
	Heavily rubbed	96.0	94.0	95.0
Gopher B	No treatment (original)	95.0	93.5	93.0
	Lightly rubbed	96.0	93.6	96.0
	Heavily rubbed	96.5	93.5	95.5

*Seven samples.

average increase in test weight for the 3 years was nearly 9 pounds per bushel. Exhibitors have long taken advantage of this practice.

EFFECT OF RUBBING OAT GRAIN ON VIABILITY OF THE SEED

The effect of rubbing oat grains on the viability of the seed is shown in Tables 5, 6, and 7. The tests were conducted in the Minnesota germinator and included six varieties that were grown for three years, *viz.*, 1935, 1936, and 1937.

TABLE 7.—*Germination tests of untreated (original), lightly rubbed, and heavily rubbed seed of six varieties* of oats grown in 1937 and stored 12 months and 16 months, respectively.*

Variety	Treatment	Percentage germination		
		Dec., 1937	Dec., 1938	Apr., 1939
Alaska	No treatment (original)	99.0	97.5	97.5
	Lightly rubbed	96.0	97.5	98.0
	Heavily rubbed	99.0	98.0	99.0
Cartier	No treatment (original)	99.0	97.5	97.0
	Lightly rubbed	99.0	98.5	99.0
	Heavily rubbed	99.0	98.0	98.0
Minota	No treatment (original)	98.0	98.0	98.5
	Lightly rubbed	100.0	98.0	98.5
	Heavily rubbed	100.0	97.5	98.5
Columbia	No treatment (original)	100.0	97.5	98.5
	Lightly rubbed	98.0	98.5	98.5
	Heavily rubbed	97.0	98.0	99.0
Markton × Idamine (C. I. No. 2570)	No treatment (original)	99.0	97.0	97.5
	Lightly rubbed	100.0	97.0	98.5
	Heavily rubbed	98.0	97.5	98.5
Gopher A	No treatment (original)	96.0	98.5	98.5
	Lightly rubbed	98.0	99.0	98.5
	Heavily rubbed	97.0	99.5	99.5
Gopher B	No treatment (original)	99.0	98.0	97.0
	Lightly rubbed	97.0	98.5	98.5
	Heavily rubbed	98.0	98.5	98.0

*Seven samples.

The data in Tables 5, 6, and 7 show that the loss in viability of the oat seed is no greater when lightly or heavily rubbed than when untreated (Fig. 2). Even the Gopher B sample harvested in 1935 that was musty when rubbed and stored, though lower in viability throughout the period of test, retained its viability equally as well as when untreated. Furthermore, the length of the storage period seemed to have little, if any, differential effect upon the viability loss of the rubbed or clipped oats. It would seem therefore that considering all the conditions surrounding these experiments, the number of varieties and harvested crops studied, the varying duration of the storage period following clipping, there is small liklihood of increasing the

rate of deterioration in viability of the oat embryo by removing the tip or "tail" of the oat hull. The embryo of the caryopsis, the really vital and essential part concerned, is situated on the opposite end of the grain, is fully protected, and is therefore apparently not affected by this treatment. In the light of these data, one might well raise the question, Is a judge of oats justified in discriminating against clipped oats whose tips or "tails" have been removed in a show sample? If the viability and seed value is not jeopardized by "clipping" as is emphasized by the above data, it might seem that the question may well be raised by the exhibitor.

The effect of rubbing oat grains on the viability of the seed is shown in Table 8. The tests were conducted in soil in the greenhouse.

TABLE 8.—*Germination tests in soil in the greenhouse of untreated (original), lightly rubbed, and heavily rubbed seed of six* varieties of oats grown in 1935 and stored 2 years and tested in January 1938.*

Variety	Treatment	Germination, %	Weak, %	Dead, %	Height of strong plants in 14 days, ins.	Height of weak plants in 14 days, ins.
Alaska	Untreated (original)	96.0	4.0	0.0	5.5	2.0
	Lightly rubbed	95.0	4.5	0.5	5.5	2.5
	Heavily rubbed	95.5	4.5	0.0	5.5	2.0
Cartier	Untreated (original)	91.5	7.0	1.5	5.0	2.0
	Lightly rubbed	93.0	6.5	0.5	5.0	2.0
	Heavily rubbed	94.0	4.5	1.5	5.5	2.5
Minota	Untreated (original)	93.5	4.5	2.0	4.5	2.0
	Lightly rubbed	93.0	6.5	0.5	4.0	1.5
	Heavily rubbed	94.0	4.0	2.0	4.0	2.0
Columbia	Untreated (original)	95.0	1.5	3.5	5.0	1.5
	Lightly rubbed	95.5	2.0	2.5	5.5	2.0
	Heavily rubbed	95.0	3.0	2.0	5.5	2.0
Markton × Idamine (C. I. No. 2570)	Untreated (original)	89.0	4.0	7.0	4.5	2.0
	Lightly rubbed	88.5	6.5	5.0	5.0	2.5
	Heavily rubbed	91.0	5.0	4.0	5.5	2.5
Gopher A	Untreated (original)	83.0	7.0	10.0	4.0	2.0
	Lightly rubbed	89.5	3.0	7.5	4.5	2.0
	Heavily rubbed	82.5	3.5	14.0	4.0	2.0
Gopher B†	Untreated (original)	66.5	10.0	23.5	4.0	2.0
	Lightly rubbed	66.0	8.5	25.5	4.0	2.0
	Heavily rubbed	73.5	9.0	17.5	4.0	2.0

*Seven samples.
†Samples slightly musty when rubbed and stored.

The seed is the same as was grown and rubbed in 1935. It was stored for 2 years, however, before being tested.

Two hundred seeds were picked at random from each of the untreated (original), lightly rubbed, and heavily rubbed samples and planted in soil in flats in the greenhouse in January. The soil was kept

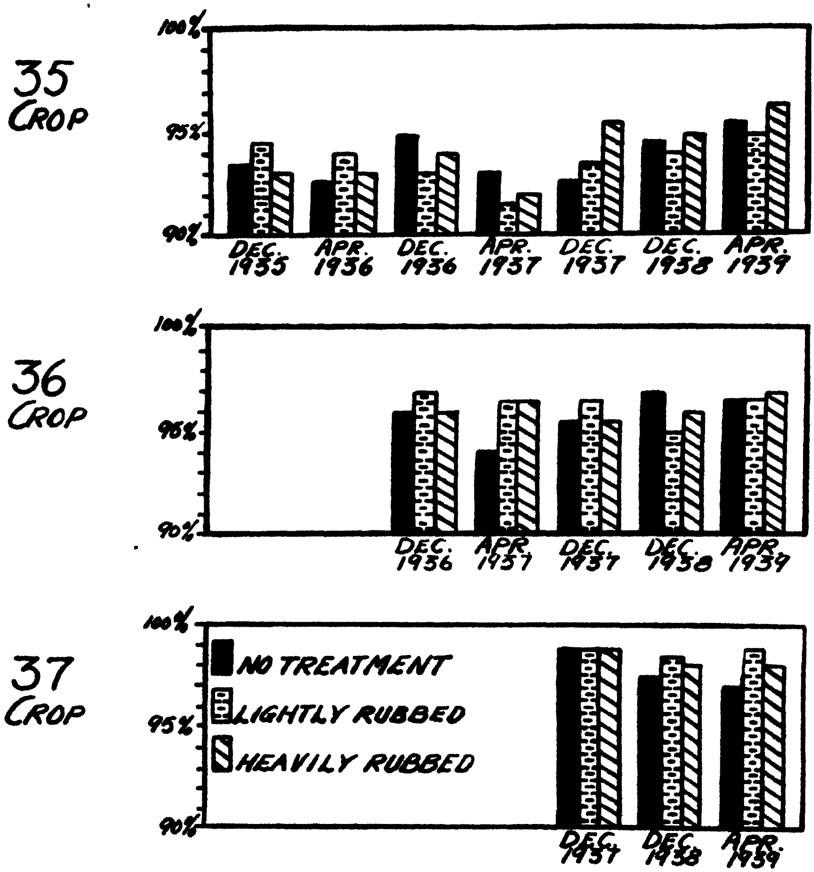

FIG. 2.—The relative germinability of untreated, lightly rubbed, and heavily rubbed oat grains of the Cartier variety from the 1935, 1936, and 1937 crops, respectively.

well wet down during the entire period of germination and growth. The temperature of the air in the greenhouse was kept at about 60° F. It will be apparent that the conditions under which these tests were conducted were not especially favorable and might even be said to approximate those under field conditions. It will be noted too that the seed had been stored for 2 years.

The results of the greenhouse tests in soil are not different from those made in the germinator. It is clearly seen that the lightly rubbed and heavily rubbed seed have in all instances germinated quite as

well as the untreated seed. Furthermore, additional evidence is here afforded on the number of weak and dead seeds present, also on the subsequent growth and vigor of plants as measured by the height of the plants, from both the strong and weak plants. From these rather limited data, it will be noted that there is no measurable difference in the viability of the untreated and the rubbed grain.

SUMMARY

The grain of six varieties of oats was treated (lightly and heavily rubbed) to remove tips or tails of the hull and other extraneous materials. Test weight and viability tests were conducted.

The test weight was increased on the average from 21.8 to 37.4%, or 7.3 to 10.2 pounds per bushel. The higher percentages occurred in the lighter weighing samples.

The germination tests carried out in the Minnesota germinator and in soil in the greenhouse showed no indication of loss in viability of the seed that was traceable to the rubbing or clipping. These results were consistent in all samples stored for periods ranging from 4 months to more than 3 years duration.

GROUND RAINFALL UNDER VEGETATIVE CANOPY OF CROPS[1]

J. L. HAYNES[2]

THE influence of vegetative canopy on character and amount of ground rainfall has been found to affect the non-capillary porosity, percolation rate value, and particle arrangement and coherence as reported by Hendrickson (2),[3] Neal (5), Lowdermilk (4), and Wollny (6, 7) in studies relating to impaction, soil percolation, and effect of vegetative cover. The amount of ground rainfall directly affects the amount of moisture available for plant use as well as potential supply of water contributing to run-off. Distribution of ground rainfall beneath the vegetative cover affects the local availability of water to the roots and influences turbulence of flow and character of drainage pattern during run-off. Detailed descriptions of the character of ground rainfall are needed in development of methodology of hydrograph analysis where run-off from different vegetative covers are considered.

Investigations of the character of ground rainfall under forest canopy were made by Horton (3) in 1919, but determinations of character of ground rainfall under crop cover have been inadequate to meet the needs of certain phases of present development in applied hydrology.

Results reported herein show measurements of the components of ground rainfall over a period of 3 years of study. Records for the 1937 growing season, taken at Bethany, Mo., under alfalfa, oats, corn, and soybeans, and for selected periods under timothy, bluegrass, and wheat, have been reported in mimeographed form (1). The study was carried forward during 1938 and 1939 at Sussex, N. J., for the crops of alfalfa, oats, corn, clover (Ladino), timothy, and bluegrass for the entire growing season.

PROCEDURE

The character of ground rainfall is such that it does not readily lend itself to accurate measurement. Specialized equipment, therefore, had to be developed for purposes of the investigation.

Canopy penetration was measured separately from stem water, both because it is difficult to measure these components simultaneously with a single catchment basin and because the effect of the two components upon ground rainfall impaction and distribution is notably different. Water running down the plant stalks was diverted into catchment basins by means of a funnel-like collar sealed to the stem by wax.

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[1]Joint contribution from the U. S. Soil Conservation Service, Office of Research, and the New Jersey Agricultural Experiment Station, New Brunswick, N. J. Also presented at the annual meeting of the Society held in New Orleans, La., November 22, 1939. Received for publication November 23, 1939.

[2]Junior Soil Conservationist, Soil Conservation Experiment Station, Sussex, N. J.

[3]Figures in parenthesis refer to "Literature Cited", p. 184.

Canopy penetration under corn was measured by means of galvanized metal pans 4 inches deep and 42×42 inches wide which were placed between the drill rows.

Canopy penetration under all crops except corn was measured by means of a series of V-shaped copper troughs 24 inches long, 1 $\frac{3}{64}$ inches wide, and 1 inch deep, which were placed on the ground beneath the plants. The catchment gages discharged into buried concentration units where the catch was measured.

Under mass crops, distribution of ground rainfall was measured with a gage consisting of concentric collecting units, while under row crops it was measured with parallel units. The collecting units were spaced at uniform distances from the stem for individual plants and from the drill row for row crops.

During two of the three years of record, intensity recorders were installed to receive flow from canopy penetration and stem water catchment units. In order to check consistency of results canopy penetration gages were installed in duplicate on all crops and stem water installations in triplicate during the last year of records.

Examination of records from the replicated installations showed that canopy penetration measurements checked very closely. Stem water measurements, on the other hand, were extremely erratic, so much so that it is apparent that a block involving a considerably larger number of this type installation would be necessary to obtain an exact quantitative measurement of the stem water. A part of the error involved in measuring the stem water may have resulted from the practice of attaching measuring equipment only to sturdy individuals. Intensity records from stem water attachments showed the shape of the intensity curve, but in general the amounts recorded were obviously in excess of the average for field conditions. These curves will be presented at a future date in connection with problems related to hydrograph analysis. In view of the erratic nature of the stem water measurements these are presented separately from canopy penetration figures which latter were consistent in replication. Intensity records presented herein were selected from records of small storms where the contribution of stem water to ground rainfall was minimized.

Quantative measurements of vegetative cover were made by use of pantograph and planimeter. As used in this discussion, density measurements are expressed as unit of ground area divided into the plant surface above it, considering the area of one side of all leaves and the entire stem surface. Thus a crop having a density of 6.0 would bear 6 square feet of plant surface per square foot of ground surface. Foliage cover, sometimes termed ground cover, is expressed as percentage of ground surface covered by the projected crop canopy. A stand having 75% foliage cover would thus shade three-fourths of the ground at high noon.

RESULTS AND DISCUSSION

A summary of ground rainfall measurements for all the crops which were studied appears in Table 1. It will be noted that the mass crops, bluegrass, clover, timothy, and alfalfa, indicated relatively smaller amounts of ground rainfall than did row crops. The records for 1937 were taken at Bethany, Mo. The 1938 and 1939 records were collected at Sussex, N. J. It should be pointed out that records of stem water, when collected, frequently indicated negative results of interception for individual storms. At the initial stages of the experiment, wax-floored catchment basins were placed under oats,

bluegrass, and timothy for the purpose of determining whether significant amounts of water reached the ground by passing down the stem. During the period of these tests no rains exceeding 0.50 inch were recorded, and the equipment showed no stem water during this period. However, when intensity records of subsequent rainfall in excess of 0.50 inch are plotted, there are definite indications that these crops do pass water to the ground via the stem. For this reason percentages shown which exclude stem water measurements are in excess of the total ground rainfall to be expected under field conditions.

Data for all storms, regardless of size or stage of crop growth, are included in the results shown in Table 1. These represent full growing season records for alfalfa, corn, clover, soybeans, and oats. Full growing season records for bluegrass are included in the 1938 and 1939 results. Results for 1937 under bluegrass and timothy represent storms during the month preceeding harvest of the respective crops. Records for timothy during 1938 and 1939 were discontinued at the date of the first harvest of the crop.

TABLE 1.—*Precipitation and ground rainfall records during the respective experimental periods for each crop studied.*

	Year	Alfalfa	Corn	Clover	Bluegrass	Oats	Timothy	Soybeans
Precipitation, in.	1937	12.31	7.12	—	0.98	6.77	1.11	6.25
	1938	32.82	12.82	23.21	29.65	12.39	10.93	—
	1939	11.99	6.93	11.08	11.99	3.15	3.94	—
Total inches		57.12	26.87	34.29	42.62	22.31	15.98	6.25
Canopy penetration, in.	1937	7.25	4.84	—	0.82	6.34	0.82	4.06
	1938	21.23	9.10	14.00	13.76	9.08	6.58	—
	1939	8.48	4.95	7.93	4.62	2.53	3.17	—
Total inches		36.96	18.89	21.93	19.20	17.95	10.57	4.06
Stem water, in.	1937	0.76	1.18	—*	—*	—*	—*	1.28
	1938	5.84	3.18	—*	—*	—*	—*	—*
	1939	1.24	1.76	—*	—*	—*	—*	—*
Total inches		7.84	6.12	—	—	—	—	1.28
No. of observations		125	51	69	73	69	43	18
Total interception, including stem water, % of rainfall		21.6	6.9	—*	—*	—*	—*	14.6
Total interception, excluding stem water, % of rainfall		35.3	29.7	36.0	55.0	19.5	33.9	35.0

*No stem water records taken.

Distribution of ground rainfall under row crops is illustrated by records from soybeans shown in Fig. 1. It will be noted that more than twice as much precipitation falls in the center of the interspace than adjacent to the row. Stem water is not considered in this graph. The

canopy apparently tends to pass precipitation from leaf to leaf in a shingle effect toward the interspace. This tendency was pronounced even after the vegetation covered the entire interspace. A similar character of distribution of ground rainfall was found under drilled oats. When wind direction during the storm was at right angles to the row direction, a concentration of ground rainfall was recorded on the leeward side of the interspace.

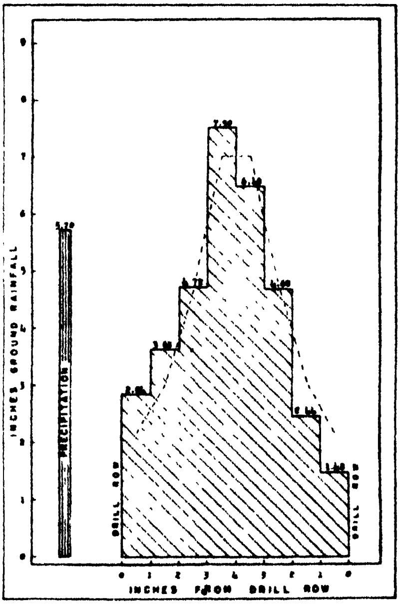

FIG. 1.—Distribution of ground rainfall between drill rows of soybeans. The dotted line represents average distribution in the interspacing.

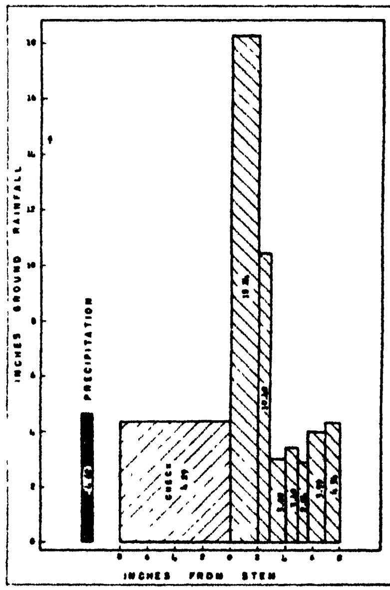

FIG. 2.—Distribution of ground rainfall under single alfalfa plant.

Distribution of ground rainfall under a single plant is illustrated by alfalfa, results of which are shown in Fig. 2. This graph includes stem water flow in the unit adjacent to the stem. The higher precipitation shown in the outer units probably represents the shingle effect of canopy upon rainfall, which was shown under drilled crops. Results from individual storms indicated more ground rainfall on the windward side of the plants. The edge of the canopy was limited to an 8-inch radius from the stem.

An increase in percentage of interception was noted with increase of vegetative growth. Fig. 3 shows interception by 10-day periods previous to harvest dates for the crops under study. Storms having less than 0.05 inch precipitation were excluded from figures used in compilation of these curves. Measurements of stem water were also omitted in order to make the curves for each crop comparable.

Ground rainfall intensities under various crops selected from small storm periods are shown in Fig. 4. Intensity of ground rainfall fre-

quently exceeds the actual rainfall during the periods following high precipitation intensities. Peak precipitation intensities tend to be lowered by vegetative canopy which spreads the amount of rainfall

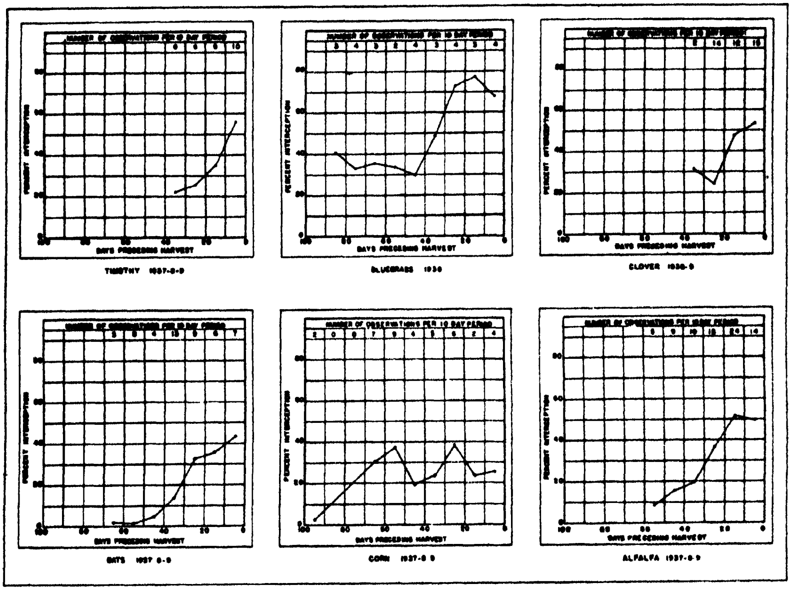

FIG. 3.—Relationship of amount of canopy penetration to vegetative development for various crops.

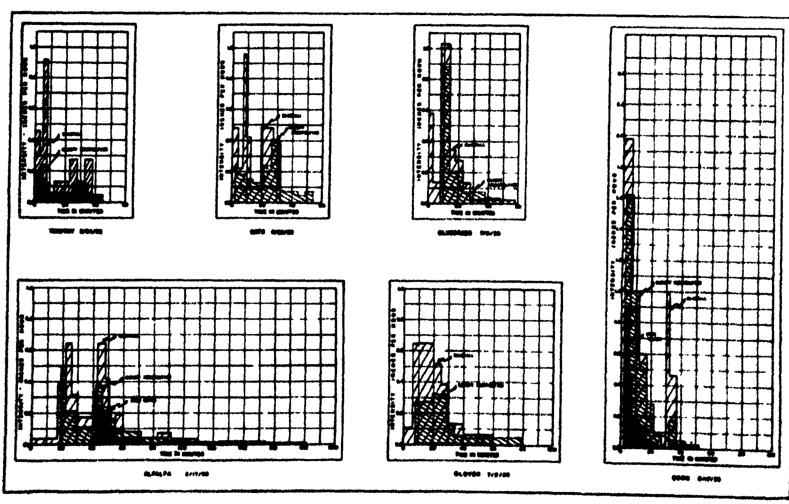

FIG. 4.—Intensity of rainfall, canopy penetration, and stem water under crops from selected storm periods during maximum vegetative development. Solid lines represent rainfall, dotted lines show canopy penetration, and broken lines show stem water.

over a longer time period by detention on the vegetative cover. It is pointed out, however, that localized spots beneath the canopy experience considerably higher intensity rates than is caused by the actual precipitation. This localized increase of intensity is dependent entirely upon the character of plant growth which, according to the nature of the plant, may concentrate ground rainfall at the stem or at the edge of individual plant canopies. In this relationship it is to be kept in mind that impact of rainfall is normally broken by vegetative canopy before reaching the ground even at points of high ground rainfall concentration.

ALFALFA

Alfalfa used in this study was managed as hay, being harvested at 18 to 20 inches when the plants started to bloom. Average density of cover by planimeter readings was 7.0 at stages of maximum vegetative development. During certain types of storms, precipitation finds a resting place on both sides of the leaf, in which case a plant surface equal to almost twice the density figure named is potentially available to interception storage and, obviously, to evaporation exposure. Foliage cover reached 90 to 100% before cuttings.

Interception immediately following mowing was relatively small, increasing with vegetative growth following cutting, as shown in Fig. 3. Intensity records from canopy penetration measuring equipment showed higher percentage of interception at the initial stage of the storm but that interception storage is not necessarily completed at the start of ground rainfall. It will be noted from Fig. 4 that a considerable amount of water reaches the ground by passing down the stem, even during the low intensity storm selected for this graph.

CORN

Corn under which ground rainfall measurements were made was in 42-inch drill rows, with average 14-inch hill spacing for the 1937 records and 9-inch spacing for the 1938 and 1939 records. Density and foliage cover were somewhat greater than measurements from comparable stands of checked corn.

Corn reached a height of 3 feet before rainfall in measurable quantities was intercepted by the crop canopy. At the period of maximum vegetative development, corn had 55 to 65% foliage cover, density of 2.4, and a height of 8 feet. As leaves matured and broke toward the end of the season, foliage cover was reduced. The plant surface of corn, as compared with alfalfa, is not well distributed over the ground due to the character of the vegetative growth.

The amount of water reaching the ground by following the corn stalk is relatively large. This in part accounts for the irregularity of the curve of seasonal interception shown in Fig. 3 which does not include stem water measurements. Records from canopy penetration measuring equipment showed a higher percentage of interception at the initial stage of the storm but showed also that interception storage is not necessarily completed at the start of ground rainfall. As shown in Fig. 4, a considerable amount of water reaches the ground by passing down the stem. Frequently stem water flow started considerably

in advance of canopy penetration catch. The nature of the final stage of the storm period appears to have considerable effect on the total interception.

SOYBEANS

Soybeans were drilled in 8-inch rows. At maximum vegetative development they reached a density of 4.2, a foliage cover of 95%, and a height of 38 inches during the single year of observations. Approximately one-third of the precipitation was conducted to the ground by the stem when the plants had reached full maturity. Intensity of canopy penetration seldom equalled that of actual precipitation.

OATS

Oats, under which interception measurements were made, were drilled in 8-inch rows. At maximum vegetative development measurements showed a density of 11.6 and foliage cover of 55 to 65%. Although density of vegetative cover is high, the bulk of plant surface is concentrated in the drill rows leaving considerable areas of exposed ground in the interspace. Intensity of ground rainfall under oats frequently equals that of precipitation during prolonged storm periods.

Measurements of canopy penetration under wheat during a 30-day period immediately preceeding harvest showed 19.9% interception which compares closely with the longer period recorded under oats.

TIMOTHY

Timothy reached a maximum density of 17.3, foliage cover of 80 to 95%, and height of 25 to 35 inches during the course of study. A large portion of the plant surface is limited to the region of the plant stem although the ground surface is generally well covered by leaf area as indicated by the high foliage cover. Measurements of interception under timothy made at intermittent periods subsequent to harvest showed negligible interception until fall growth. Timothy was harvested in June during this period of study.

BLUEGRASS

Bluegrass used in the 1937 measurements did not include ground litter. Maximum foliage cover was 25%. The catchment units were placed beneath the grass litter for the 1938 and 1939 studies. The crop was harvested in June during 1938 and was allowed to grow rank without cutting for the 1939 season during which time the grass reached a length of 18 inches and lodged 10 inches over the equipment. Measurements made at the time of most heavy growth in 1939 showed a density of 12.9, including the fallen blades which made up the ground litter and 100% foliage cover.

CLOVER

The clover under which measurements were made was a dense stand of Ladino, a mammoth white clover. The stand reached a maximum height of 24 inches in 1938 and 16 inches in 1939. The growth

recovery following harvests was rapid, normally providing a complete foliage cover within 3 weeks. No density measurements were made on this crop.

SUMMARY

It is obvious that vegetative canopy may influence soil and water losses in four ways, namely, by alteration of intensity of ground rainfall, by alteration of total amount of water available to carry silt load, by alteration of impact, and by character of distribution of ground rainfall.

It is likewise apparent that water which reaches the ground by passing down the stems will exert less impact than that which falls from the canopy, and, in turn, that canopy penetration will have less impact than actual precipitation. The functions of vegetation as obstruction to overland flow are not considered in this discussion.

Of the crops studied, water reaches the ground under mass crops with less potential energy for moving soil than under row crops. Reduction of total ground rainfall is greater, intensity of ground rainfall is less, energy of initial impact is lessened, and distribution of ground rainfall is fairly uniform, except for greater volumes at the stem and at the periphery of individual plant canopies under mass crops than under drilled crops. Because of the large number of stems per unit area of mass crops, the stem water is better distributed over the ground surface than under corn, for instance.

Amount of canopy penetration under corn at maximum vegetative development is reduced from that of actual precipitation. Since a relatively large amount of direct precipitation reaches the ground, impact is considerably higher than under alfalfa. The large amounts of stem water would be expected to influence soil and water losses, evidence of which has been observed in the field in the form of rivulets on either side of the corn rows drilled up and down the slope.

Intensity of canopy penetration under oats and soybeans is reduced, although total ground rainfall approaches that of actual precipitation. Impact is much reduced after the crop has reached full vegetative development. In distribution, ground rainfall tends to concentrate water between the rows, thus promoting turbulence of flow in the interspace.

CONCLUSIONS

1. Measurements of ground rainfall under various crop canopies have been made over a 3-year period of study.
2. Interception was found to increase directly with vegetative cover.
3. Intensity of ground rainfall is in general less than that of actual precipitation.
4. Distribution of ground rainfall is influenced by the character of vegetative growth.
5. A portion of ground rainfall under crops having stems or stalks is conducted to the ground by the plant stem.
6. Foliage cover, density, height, and character of vegetative growth appear to contribute to the effect of vegetative canopy on character and amount of ground rainfall.

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THE WELFARE OF CATTLE ON FLORIDA PASTURES[1]

R. B. BECKER AND J. R. HENDERSON[2]

LIVESTOCK in the bluegrass region of Kentucky, the Shenandoah Valley of Virginia, and parts of England are world famous for their excellence from many standpoints. Animals thrive in those regions because the forages grown on the soils contain optimum amounts of the nutrients essential to the welfare of animal life. In other regions, the development of livestock depends somewhat upon the degree that the soil has limited the level of some essential element in the forages utilized as feed. The fact that fertility of the land limited the thrift of livestock in any particular region was recognized generations ago by the early agricultural writers.

In 1776, John Mills (16)[3] attributed to mismanagement more than to infertility the stinted size of some of the farm stock of England.

William Aiton (1) associated the kind of soil with thrift of the cattle of southwestern Scotland.

Even on the Island of Jersey, LeCouteur (13), Secretary of the Royal Jersey Agricultural and Horticultural Society, observed that, "In so small a spot as Jersey, it is difficult to cross the breed essentially—a great step towards it is gained by crossing cattle bred in the low rich pastures with those of the exposed hills on the western or northern coasts: these being smaller, finer boned, of a more hardy constitution, and feeding on a short rich bite, impart strength of constitution and hardihood to the larger and more delicate animals of the sheltered low grounds."

Two of the leading authorities on livestock a century ago were David Low, Professor of Agriculture in the University of Edinburgh, and William Youatt of England. Low (14) wrote that, "It is upon the supply of food that the size of the animals seems mainly to depend. Wherever food is supplied in abundance, the ox becomes enlarged in bulk; and wherever food is deficient, whatever be the nature of the climate, his size becomes less."

Youatt (19) wrote in the same vein as follows: "The breeds of cattle, as they are now found in Great Britain, are almost as various as the soil of the different districts, or the fancies of the breeders. ....Thence it resulted, that in Devon, in Sussex, in Wales, and in Scotland, the cattle have been the same from time immemorial; while in all the eastern coast, and through every district of England, the breed of cattle degenerated, or lost its original character; it consisted of animals brought from every neighboring and some remote districts, mingled in every possible variety, yet conforming itself to the soil and climate."

The above-mentioned writers dealt with areas usually considered adequate for the production of cattle. At the other extreme, on defi-

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[3]Figures in parenthesis refer to "Literature Cited", p. 188.

nitely deficient areas, infertility of the soil limits the composition of the grass in some essential element to the extent that the thrift of livestock is affected to a greater degree.

Thus, Hogg (12) wrote of an anemia called "pining" among sheep on the northern slope of the Cheviot Hills on the Scottish border. An unnamed writer (2) in the same issue of the *Quarterly Journal of Agriculture* stated that pining increased especially on astringent pastures such as those on the syenitic porphyry of the Cheviots, and that it is not known on the clay slate range of the Lammermuir Hills, nor is it found on heath or green pastures on a calcareous (red) sandstone formation.

McGowan and Smith (15) studied the same area a century later, and observed the practice of the stockmen to change to new pasturage once or twice in the year. It was a common belief that otherwise the whole stock would die out in less than two years if they were kept constantly on the same ground.

The virgin fertility of a pasture soil is related directly to the welfare of the cattle grazing thereon. The kind and amount of plant food available in a virgin soil determine both the kind and amount of native forages produced. This is particularly true on certain virgin soils of the coastal plains in the southeastern states.

In the spring of 1930, before mineral supplements were used generally in Florida, Camp (10) studied 7,100 head of cattle on 110,000 acres of range and pasture land, including all of the native cattle then in one county in herds of over 50 head. The records were sorted into four groups in relation to the types of native pasture over which the cattle grazed. The pasture types were designated as flatwoods (mainly palmetto flatwoods), deep sandy or blackjack lands, the wet prairie soils high in organic matter, and hardwood hammock lands. The soils represented in these several types of pastures were as follows:

Flatwoods—Leon, Portsmouth, and Plummer fine sands
Blackjack—Deep phase of Norfolk fine sand
Prairie —Bayboro fine sandy loam and Bayboro loamy fine sand
Hammock—Fellowship, Hernando and Gainesville fine sandy loams and Fellowship clay loam.

By actual counts of cattle at the dip vats and by interviews with individual owners, Camp obtained records concerning the numbers of calves produced, raised, and marketed per hundred breeding cows, and the market returns per animal sold. These records were analyzed to determine the gross returns per breeding cow on each class of range (Table 1).

Undoubtedly a number of other factors besides soil type were involved in the returns. The class of pasture and all that is associated with it was the largest contributing factor involved. The soil and moisture supply affected the type of native grazing crop, its amount over the grazing period, the composition of the forage, and the efficiency of its utilization by the cattle.

Information supplied to the senior author during 1929 and 1930 by cattlemen over a wider area was substantiated by Camp's observations. The nutritive value of the native vegetation growing on certain

TABLE 1.—*Returns per breeding cow on different types of range in Florida.*

Range	Average calf crop, %	Animals marketed, %	Average value at 2½ years*	Gross annual return per breeding cow
Flatwoods	34.4	34.20	$30.20	$10.33
Blackjack	37.1	35.61	23.75	8.46
Prairie	54.1	53.80	35.50	19.10
Hammock	70.6	71.60	36.50	26.13

*Mostly sold as butchered beef.

soils limited the number of calves produced, the number that survived, the ability of the dams to provide milk, and the resulting weight and grade of the calves at market age. At the same time, dairymen located on some types of land were quite successful in raising calves, while on other areas the losses of calves were so great that other dairymen there had ceased trying to raise their own replacements. The fencing of pastures and restricting the soil type over which cattle grazed aggravated the condition.

An investigation of the cattle on the various classes of pasture lands led to integration into a number of problems, some occurring separately and others overlapping one another. Several of these causes are as follows: (a) Inadequate intake of calcium; (b) inadequate intake of phosphorus; (c) inadequate intake of iron, or of iron and copper; and (d) inadequate intake of cobalt, iron, and copper, or a combination of these with low cobalt.

Inadequate calcium intake (3, 6) was seen among Jersey cows that were fed silage and hay grown on quite acid Alachua fine sand, Norfolk fine sand, and Arredonda fine sand.[4] The correction of this condition by the use of feeding bonemeal, and more recently by a combination of bonemeal and marble dust (calcium carbonate), was accompanied by greater strength of bones and a marked response in milk yields.

Inadequate phosphorus intake (7, 9) was seen among farm cows and range cattle subsisting entirely on native plants growing on Norfolk, Ruston, and Orangeburg fine sandy loams in one area and on Leon and Plummer fine sands in another. Fractured bones and depraved appetites were encountered among cows under such conditions. Cattle receiving phosphorus supplement in the form of bonemeal ceased chewing bones, leather, wood, etc., and tended to fatten under conditions which hitherto had caused them to remain spare or thin.

Inadequate quantities of iron, copper, cobalt, or combinations of these in the forage have been observed to restrict growth and welfare of livestock on several types of soils (5, 8, 17).

Anemic cattle on one pasture occupying a river terrace on which the dominant soil is Kalmia fine sand recovered when supplied only a commercial grade of ferric ammonium citrate. On other pastures of Leon fine sand and the flat phase of St. Lucie fine sand, particularly, responses of dairy heifers, family cows, and range cattle were de-

[4]Alachua and Arredonda are tentative series names.

layed until copper sulfate was added to the ferric ammonium citrate in a ratio of 1 part of copper to 50 parts of iron.

A supplement called "salt sick" mineral was used commercially over the state in two mineral mixtures. The second formula, with a reduced amount of salt, was used with cattle close to salt marsh or brackish water areas. The formulas were as follows:

	No. 1	No. 2
Common salt	100	50
Bonemeal	None	50
Red oxide of iron	25	25
Pulverized $CuSO_4$	1	1

At the Florida Experiment Station, controlled feeding trials were conducted using separate pure minerals to supplement Natal grass hay and corn grown on a light Norfolk fine sand. Jersey calves in these trials ceased growth when 5 to 8 months old. Only one calf thrived with the iron-copper supplement until, following a clue from Australia (4, 11, 18) traces of a cobalt salt were added to the ration by Dr. W. M. Neal (17).

Reports of failures of livestock to respond to the use of "salt sick" mineral No. 1 were received from stockmen having cattle on deep Norfolk fine sand in certain areas, Lakewood fine sand, Leon fine sand, Blanton fine sand, and on one area of muck. Addition of an ounce of cobalt sulfate to the No. 1 iron-copper supplement used on these areas was accompanied by prompt responses by cattle, goats, and swine under observation in these cooperative field investigations.

Thus it is seen that cattle dependent on the forage grown on any definite area are limited in their development and activity according to the amounts of certain minerals contained in that forage. A full understanding of the limitations of the soils within the available pasture areas in supplying these minerals places the stockman in a position to use the correct supplements in his stock feed or mineral mixture, or to manage his soils in such a way that these minerals may be obtained from the forage produced thereon.

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RUSSIAN THISTLE SILAGE[1]

F. T. DONALDSON AND KENNETH J. GOERING[2]

SINCE its introduction into South Dakota about 1873 (8),[3] the Russian thistle (*Salsola pestifer* Aven Nelson) has become widely distributed in the United States and Canada. Due to its high drought resistance, it flourishes in semi-arid regions and during abnormally dry years is often the only plant available for emergency feed.

The value of the Russian thistle for pasture or for hay depends in a large measure upon the maturity of the plant when it is grazed or cut. The young plant is quite succulent and contains a high percentage of protein; but as the plant matures hard, spiny tips develop, the percentage protein decreases (10, 4), and the stems become hard and fibrous. The possibility of preserving the young succulent plants by ensiling was suggested to the authors[4] and this paper constitutes a report of laboratory trials on several types of Russian thistle silage.

The small amount of silage which can be prepared in laboratory trials limits the usefulness of the data which can be obtained from such tests. Naturally no feeding tests can be conducted and little information can be obtained which will determine the value of the process from an economic viewpoint. The object of this study, however, was to determine the possibility of preserving the immature plants in a palatable state. Such an objective involves a study of the chemical characteristics of the silage, and it has been demonstrated that laboratory trials are adequate for this purpose (1, 3).

CHEMICAL COMPOSITION OF RUSSIAN THISTLES

The Russian thistles used in this study were cut on August 27. The spines on this date were just starting to feel prickly but were still fairly soft. Representative samples containing approximately 80% moisture were analyzed for the usual feed values and also for minerals. The results of these analyses are listed in Table 1. For comparison, the average values obtained from the analyses of 89 samples of Montana-grown alfalfa (7) are also included in the table.

The analyses show that the young thistles are equal to the alfalfa in protein and ether extract content and have a more favorable carbohydrate-crude fiber balance. This apparent superiority may be offset by the high potash content which is the probable cause of the laxative effect of the thistles. In view of the apparent phosphorus deficiency in certain Montana forages, the high P_2O_5 content of the thistle may enhance its value as a feed.

PREPARATION OF SILAGE

Due to the high protein and high ash content of the thistles, it was

[1]Contribution from the Chemistry Department, Montana State College, Agricultural Experiment Station, Bozeman, Mont. Paper No. 110, Journal Series. Received for publication November 29, 1939.

[2]Assistant Professor and Assistant Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 193.

[4]This work was carried on at the suggestion of Mr. Edmund Burke, Chemist, Montana Agricultural Experiment Station.

considered unlikely that silage prepared without the addition of some acid or acid-forming substance would be successful. Hydrogen-ion concentration is the prime factor in the successful preparation of silage and in order to develop the required acidity, the crop must possess a relatively high carbohydrate-protein ratio. During the last decade considerable progress has been made in the preservation of high protein forage crops by ensiling with an acid or with some material rich in fermentable carbohydrates (11, 9, 2). Wilson (14) has determined what are essentially the relative buffer capacities of various plant materials and found that high protein materials require more acid per unit pH change than low protein material.

TABLE 1.—*Chemical analyses of Russian thistles and alfalfa hay, dry basis.*

Constituent	Russian thistle, %	Alfalfa, %
	*Feed Analyses**	
Crude protein (N × 6.25)	16.2	16.5
Ether extract	1.7	1.5
Crude fiber	20.7	33.4
Ash	19.5	8.7
Nitrogen-free extract (by difference)	41.9	33.9
	Mineral Analyses†	
CaO	1.84	2.02
MgO	1.93	0.48
SO_4	0.84	—
P_2O_5	0.78	0.42
K_2O	8.25	—
R_2O_3	0.55	—
Siliceous matter	0.42	—

*Analyses of sample of Russian thistle used for making silage and average of 89 samples of alfalfa hay.

†Analyses of sample of Russian thistle used for making silage and average of 10 samples of alfalfa hay.

The Russian thistles were cut into pieces ½ inch long or less and packed as tightly as possible into ½ gallon jars holding approximately 1,400 grams of the green chopped material. Three types of silage were prepared. The first was prepared with thistles plus 3% sucrose, the second with thistles alone, and the third with thistles plus 1% H_3PO_4. Escape valves were provided on all the jars to prevent the intake of air. The jars were left in the laboratory (about 22° C) for 7 months when they were opened and the silage analyzed.

None of the three types of silage appeared to be spoiled, but the silage made without the addition of a preservative was darkest in color and possessed a sharper odor of acetic acid than did the other two.

ANALYSIS OF SILAGE

The silage was ground in a Nixtamal mill and water extracts were made according to the method of Woodman (15). The pH was determined with a glass electrode and sugars by the alkaline ferricyanide method (5). Volatile bases, amino acid, total acidity, and

volatile and non-volatile organic acids were determined by Woodman's (15) modification of Foreman's (6) method. The results of these analyses are given in Table 2.

TABLE 2.—*Analyses of Russian thistle silage prepared in three different ways, wet basis.*

Constituent	Thistles plus 3% sucrose	Thistles untreated	Thistles plus 1% H_3PO_4
pH of expressed juice	3.95	4.78	4.05
Volatile organic acids as % acetic	0.38	0.47	0.33
Non-volatile organic acids as % lactic	2.08	0.87	2.09*
Ratio non-volatile organic acids to volatile organic acids	5.5	1.9	6.4*
Amino acids as % crude protein	0.78	0.90	0.56
Volatile bases as % crude protein	0.31	0.33	0.20
Total nitrogen as % crude protein	3.29	2.94	2.99
Volatile base nitrogen as % of total nitrogen	9.4	11.3	6.8
Amino acid nitrogen as % of total nitrogen	23.7	30.6	18.6
Volatile base plus amino acid nitrogen as % of total nitrogen	33.1	41.9	25.4
Ratio amino acid nitrogen to volatile base nitrogen	2.6	2.7	2.7
Dry matter, %	20.7	17.1	17.0
Total sugar as % invert sugar	1.84	0.37	0.35

*These values include the added H_3PO_4. Correcting for the H_3PO_4 gives a value of 0.54% lactic acid.

DISCUSSION OF RESULTS

ACIDITY AND PH

It has been demonstrated that pH of silage is the best single indication of quality (13). Above a pH of 4.2 there is an increasing tendency for the butyric acid type of fermentation to take place with its accompanying chemical changes which lead to putrefaction. A pH of 4.78 for the untreated silage indicates that this material came dangerously close to spoiling. The pH values for the other two types are satisfactory and show that they were preserved with some margin of safety.

As might be expected, the sugar silage contained the largest amount of lactic acid and had the highest ratio of non-volatile to volatile organic acids. A high value for this ratio indicates good quality silage, for lactic acid is a stronger acid than either acetic or butyric and produces a higher hydrogen-ion concentration in the silage. When an inorganic acid is added, the lactic-acetic acid ratio is not necessarily indicative of quality, for in this case the silage is brought rapidly to a low pH value by the inorganic acid, and large amounts of lactic acid are no longer required to prevent the butyric acid type of fermentation.

VOLATILE BASES AND AMINO ACIDS

Even in good silage a surprisingly large proportion of the protein undergoes varying degrees of breakdown. Most of the decomposition products are either volatile bases or amino acids and hence determinations of these two types of compounds afford a reliable measure of protein decomposition. It is probable that the formation of amino

acids involves little loss in feeding value, but it is questionable if volatile bases are of much value (12). Volatile base formation was greatest in the untreated silage and least in the acid silage, showing the effectiveness of the acid in checking protein decomposition. This is shown even better by the data giving the sum of the amino acid and volatile base nitrogen as percentage of total nitrogen. In the untreated silage 41.9% of the total nitrogen was present as volatile bases or amino acids, while in the acid silage these decomposition products represent only 25.4% of the total nitrogen. The figure for sugar silage is somewhat higher than that for acid silage, indicating that the acid treatment is more effective in preventing protein decomposition. Although Watson and Ferguson (12) have shown that the amino acid nitrogen is equivalent in nutritive value to the true protein nitrogen in the diet of the dairy cow, it must be realized that excessive formation of soluble amino acids may result in losses through the juice which drains from a silo.

SUGARS

Only small amounts of sugars were present in the untreated and acid silage, but the sugar silage contained 1.8%. This indicates that the 3% sucrose added was considerably in excess of the amount necessary for adequate lactic acid production. In actual practice the sugar necessary to preserve high protein material is usually added in the form of molasses.

SUMMARY

1. Analyses of Russian thistles showed these plants to be equivalent to alfalfa in protein and fat content and superior in their carbohydrate-crude-fiber ratio. The thistles had a high mineral content with the K_2O running over 8%. It was pointed out that the high P_2O_5 content (0.78%) may enhance the feeding value of the thistles in areas known to produce phosphorus-deficient forages.

2. In order to determine the possibility of preserving the immature plants in a succulent condition, laboratory trials were made of three types of Russian thistle silage. The first consisted of thistles plus 3% sucrose; the second, untreated thistles; and the third, thistles plus 1% H_3PO_4. Chemical analysis of the silage indicated that good silage could be prepared with the addition of either sugar or H_3PO_4, but that poor silage would probably result from the use of untreated thistles.

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STUDIES OF FRENCHING OF TOBACCO WITH PARTICULAR REFERENCE TO THALLIUM TOXICITY[1]

C. E. BORTNER AND P. E. KARRAKER[2]

STUDIES at the Kentucky Agricultural Experiment Station have been reported showing that frenching of tobacco is related to the reaction or lime content of the soil and to the soil nutrient supply (2, 8).[3] Later observations agree for the most part with these findings. There was considerable frenching in Burley tobacco on various plots of the Greenville soil experiment field in 1938, the extent depending on the plot treatment. The extent in various plots was determined on July 30. None was present on five unlimed plots, one of which had received no commercial fertilizer and the others varying nitrogen, phosphorus, and potassium treatments. The frenching on the plots which had received ground limestone and different commercial fertilizer treatments was as follows: Superphosphate, 40% (of the plants) severely frenched; superphosphate and nitrate of soda, 13% frenched to a medium degree; superphosphate and sulfate of potash, 6% frenched to a medium degree; superphosphate, nitrate of soda and sulfate of potash, 0.7% frenched to a medium degree; and superphosphate, nitrate of soda, and double the standard application of sulfate of potash, no frenching.

In one of the publications of this Station on frenching (2), it was stated that on the Campbellsville soil experiment field frenching occurred nearly every year on the limed plots and not on the unlimed plots, and that usually the frenching was much less severe where sulfate of potash was applied. Frenching still is entirely confined to the limed plots at this field and in many years is severe on these plots receiving only limestone and phosphate but much less severe on plots where potash has been applied in addition to limestone and phosphate.

Dr. E. M. Johnson, in field studies in western Kentucky in 1938 and 1939, observed frenching in 12 farm fields. In all but two, the pH of the soil in the frenched areas was 6.0 or above, that of the two exceptions being 5.53 and 5.58. Rapid soil tests showed a low supply of available phosphorus or potassium or both in all but one of the areas and the pH of the soil of this was 6.59. Potash deficiency symptoms were present at the time of frenching in over half the instances. The tobacco was Dark Fired, or One Sucker, except Burley tobacco in one field.

However, one clear instance has come to our attention of frenching where the soil was moderately to strongly acid. This was on a plot on the Experiment Station farm to which sulfur is added as necessary

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[3]Figures in parenthesis refer to "Literature Cited", p. 203.

to hold the pH of the soil at 5.0 or slightly below. The soil, Maury silt loam, is very high in calcium, a considerable part of which is present as the native calcium phosphate compound and a probable high calcium content of the soil solution may explain the appearance of the disease on this soil notwithstanding the low pH.

In 1932 McMurtry (4) suggested that frenching might be due to thallium toxicity. It did not seem likely to us that frenching was a toxicity disease in view of the reaction or liming and nutrient relationship found, and work was not done on this point at the time. In 1934, however, Turkish tobacco plants were grown in water cultures containing thallium. A toxic condition developed in some of the plants. This resembled frenching in certain respects but was unlike frenching in others and appeared to confirm our belief that thallium toxicity was not a cause of frenching. This experiment will later be referred to more fully.

In 1935, Spencer (5) stated that frenching probably was a toxicity disease; and in 1937 (6) that the experimental evidence reported "indicates a striking similarity between natural frenching and thallium toxicity."

Further studies by the authors on thallium toxicity and frenching and on certain other points appear to substantiate our belief that thallium toxicity is not related to frenching. The results of these studies were mentioned in the 1937 report of the Kentucky Agricultural Experiment Station and are reported upon more fully in this paper. After this manuscript was prepared, the paper of Spencer and Lavin (7) appeared in which it is stated that, on the basis of spectrographic analysis, the failure of field-frenched plants to contain any thallium suggests that frenching and thallium toxicity are different diseases.

WATER CULTURE STUDIES

In 1934 Turkish tobacco was grown in duplicate water cultures in quart Mason jars containing in different cultures 0.0, 0.5, 1.0, and 2.0 p.p.m. of thallium. Thallium was added as thallium nitrate in all the studies reported in this paper. Severe chlorosis and wilting of the plants occurred in all the cultures containing thallium. These plants did not recover when changed to cultures containing no thallium. Thallium at the rate of 0.1 p.p.m. was then added to each of the check jars. In 8 days, a yellow color developed along the veins and a bluish-green color between the veins in the leaves located about midway on the stalk, but the chlorosis did not resemble frenching.

Turkish tobacco was grown in a second water culture experiment in pint Mason jars in which the effect of a strongly acid and a slightly acid culture solution was tested on thallium toxicity and its relation to frenching. The pH values of the cultures were 4.5 and 6.2 and represent the pH of soils in which we have found (2) that tobacco, respectively, does not and does french. The pH was maintained by renewing the solutions every 2 or 3 days. The nutrient solution was 0.5 gram $Ca(NO_3)_2 \cdot 4H_2O$, 0.2 gram $CaH_4(PO_4)_2$, 0.12 gram K_2SO_4, 0.05 gram $MgCl_2$, 0.0005 gram H_3BO_3, 0.002 gram $MnCl_2$, and 1.0 cc saturated solution of ferric tartrate per liter.

In each of the pH series during the first part of the experiment, there were duplicate treatments of the following thallium concentrations: 0.00, 0.005, 0.010, 0.020, and 0.060 p.p.m. The plants were about 2 inches high when placed in the cultures on May 13. Chlorosis appeared on May 20 in the jars containing 0.06 p.p.m. of thallium in the pH 6.2 series, and 3 days later in the cultures of the same thallium concentration in the pH 4.5 series. No other chlorosis developed by June 4 when the plants averaged 16 inches high. They were cut back at this time and two suckers allowed to grow on each. (See Fig. 1.)

The thallium concentration was doubled in all cultures on May 30 and again on June 12, except that the 0.06 p.p.m. concentration was increased on May 30 to 0.08 p.p.m. and on June 12 to 0.10 p.p.m. From May 27 on, phosphorus was omitted from one jar in each dupli-

FIG. 1.—Plant grown in water cultures. A, jar 9, full nutrient pH 4.5; jar 10 phosphorus deficient nutrient pH 4.5; jar 19, full nutrient pH 6.2; jar 20 phosphorus deficient nutrient pH 6.2. Each culture received 0.100 p.p.m. of thallium. B, view of growing points on jars 9, 10, 19, and 20. C, Turkish tobacco showing the yellow-vein type of chlorosis. Plant grown in a culture (pH 6.2) containing 0.08 p.p.m. of Tl as $TlNO_3$; chlorosis was produced within 2 days. Photographed 18 days after treating.

cate treatment and from June 12 on was reduced one-half in the other jar; also on June 12 the other nutrients except iron were reduced one-half in all jars. It was thought these changes might favor the development of chlorosis because they have been found to have this effect on frenching.

None of the suckers were chlorotic when they first appeared, but chlorosis developed in all the 0.10 p.p.m. thallium cultures in the period June 12 to 18, the pH of the cultures having no effect in this connection. A mild chlorosis later developed in the 0.08 p.p.m. thallium culture containing phosphorus in each pH series. No chlorosis developed in the cultures containing no phosphorus. No other chloroses had developed by June 5 when the experiment was discontinued.

The first appearance of the chlorosis was a green-yellow mottling at the base of the leaf. This then developed into either a yellow vein with green interveinal tissue or a green vein with yellow interveinal tissue. The latter type appeared in the growing-point leaves and as they grew, changed into the former. When severe, the entire plant was yellow and in some instances strap-leaves were present.

The chlorosis in none of the plants fully resembled field frenching either as it first appeared or in the older chlorotic leaves. In all cases it started at the base of the leaf or along the midvein and moved toward the leaf tip and margin, while the chlorosis in frenching appears at the tip of the leaf and moves toward the base. The thallium chlorosis also developed to a less extent in the phosphorus-deficient plants than in those in the cultures containing phosphorus, whereas the reverse would be expected for frenching.

Root deterioration was considerably greater in the phosphorus-deficient cultures than in the full nutrient. In these phosphorus-deficient cultures this deterioration was greater in the pH 4.5 series than in the 6.2 series, and greater at the higher thallium concentration than at the lower concentration. In the cultures containing phosphorus, thallium treatments produced smaller roots but no deterioration. Some previous observations of root systems of frenched tobacco plants did not indicate any direct effect of the disease on the roots.

Turkish tobacco was grown in a third water culture experiment to test the effect of renewal compared with non-renewal of the culture solution on the development of thallium chlorosis. The same nutrient salts were used as in the second experiment but each in one-half the concentration. This solution is one in which nutrient deficiencies, particularly nitrogen, develop rather quickly unless it is renewed. It was thought that, in the unrenewed solution, a thallium concentration too low to produce chlorosis in the beginning might in time, coupled with nutrient deficiency, produce a chlorosis and perhaps one similar to frenching. The renewed cultures were held at pH 6.2. The pH of the unrenewed cultures was not controlled. Concentrations of 0.04, 0.06, and 0.08 p.p.m. of thallium in duplicate treatments were used.

Plants about 1 inch high were placed in the cultures on May 25. With concentrations of 0.08 and 0.06 p.p.m. thallium chlorosis appeared within 2 and 5 days, respectively, in both the renewed and

unrenewed cultures. The plants grew out of this in the unrenewed cultures in 10 days but remained chlorotic in the other cultures throughout the experiment. With the 0.04 p.p.m. thallium concentration, chlorosis developed in the renewed solutions in 7 days, but no chlorosis developed in the unrenewed solutions. At no time was the chlorosis in any of the plants severe or similar to frenching.

SAND CULTURE STUDIES

In connection with the earlier studies, Turkish tobacco was grown in acid-treated and washed white silica sand in ½-gallon jars containing varying amounts of Iceland spar. The Iceland spar (through a 40-mesh sieve) was used instead of ordinary pulverized limestone to obtain a purer material and instead of precipitated calcium carbonate to have a material mechanically more like ordinary pulverized limestone. No plants frenched in this experiment. In other experiments with pure sand and chemicals and high-grade limestone, some frenching did occur, but the certainty of getting frenching was very much less than when similar experiments were made with river sand (2).

These jars, after the plants had been removed, were used in an experiment with thallium. Sufficient nutrient salts were added to make possible fair growth but not sufficient to prevent the development of nutrient deficiencies. The Iceland spar treatments per jar (in triplicate) in grams were none, 2, 5, 12, and 24. Two Turkish tobacco plants were set in each jar. One jar in each of the triplicate Iceland spar treatments received thallium. This was added at the rate of 0.01 p.p.m. and was repeated over a period of 2 months to give a total of 0.06 p.p.m. During this time the plants in certain jars were allowed to become nitrogen-deficient to see if this would induce the thallium chlorosis as it does frenching when other conditions are favorable. No chlorosis developed, however, either with or without thallium. The Turkish plants were removed, nitrogen, phosphorus, and potassium additions were made, and two Burley tobacco seedlings were set in each jar on April 19, 1937. On May 1, thallium was added at the rate of 0.036 p.p.m. not only to the jars receiving thallium as stated above, but also to one additional jar in each Iceland spar treatment. A severe yellow chlorosis developed in the smaller leaves of the growing points within 8 days in all the thallium-treated jars except two of those which received the thallium beginning May 1. This disappeared within 7 days. Further applications of thallium were then made over a 5-week period to give a total of 0.195 p.p.m. beginning with the May 1 addition, but no further chlorosis developed. The plants were cut back and suckers allowed to grow. Beginning when the suckers were 1 inch long, thallium was added at the rate of 0.05 p.p.m. at weekly intervals to all jars previously thallium treated to give a total of 0.20 p.p.m. of thallium per jar during the growth of the suckers. No chlorosis developed in the suckers.

A second experiment was set up with a fresh lot of pure sand, nutrient salts, and pulverized Iceland spar (through a 40-mesh sieve) to study the effect of thallium in producing chlorosis in Turkish tobacco. The nutrients added per jar were 1.00 gram $Ca(NO_3)_2$.

$4H_2O$, 0.25 gram K_2HPO_4, 0.2 gram $MgSO_4$, 0.004 gram $MnCl_2 \cdot 4H_2O$, 0.001 gram H_3BO_3, and 3 cc of a saturated solution of ferric tartrate. Additional iron was added as needed. Two plants were set per jar. Details as to the Iceland spar and thallium additions and the chlorosis produced are shown in Table 1. Again, considered in all aspects, the chlorosis did not resemble frenching.

TABLE 1.—*Chlorosis in Turkish tobacco grown in sand with varying amounts of thallium and Iceland spar.**

Jar No.	Iceland spar, gms.	Rate of thallium addition, p.p.m.	Degree of chlorosis			
			June 27	July 6	July 24	August 9
1	0	0	None	None	None	None
2	0	0	None	None	None	None
3	0	0.02	None	Mild	None	None
4	1	0.02	None	Mild	None	None
5	3	0.02	None	None	None	None
6	6	0.02	None	None	None	None
7	0	0.04	None	Medium	None	None
8	1	0.04	None	Medium	Mild	None
9	3	0.04	Mild	Medium	Medium	Mild
10	6	0.04	Mild	Medium	Mild	None
11	0	0.06	Mild	Medium	Medium	Mild
12	1	0.06	Mild	Medium	Medium	None
13	3	0.06	Mild	Medium	Medium	None
14	6	0.06	None	Mild	Mild	None
15	0	0.08	None	Medium	Mild	Mild
16	1	0.08	Mild	Severe	Severe	Severe
17	3	0.08	Mild	Severe	Severe	Severe
18	6	0.08	Mild	Mild	Mild	Severe

*The plants were set April 28, 1937. Thallium nitrate was added eight times beginning May 19. No chlorosis developed up to June 15, when the plants were cut back and suckers allowed to grow.

SOIL CULTURE STUDIES

The effect of thallium in producing chlorosis in tobacco and its relation to frenching also was studied in soil cultures. In addition treatments were included of zinc sulfate, manganese sulfate, aluminum chloride, copper sulfate, and boric acid. The soils were from (a) an area on the Experiment Station farm at Lexington, and (b) a plot receiving manure and limestone at the Mayfield soil experiment field. Tobacco has always frenched in the latter soil in the greenhouse and usually, but not always, in the former. The respective pH of these soils were 5.95 and 6.75. The treatments in triplicate with each soil were (a) none, (b) thallium, (c) zinc, and (d) a combination of manganese, zinc, boron, aluminum, and copper. The thallium additions were repeated every few days, the rate increasing during the experiment as follows: December 14 to January 29, 0.325 p.p.m.; January 30 to February 12, 0.650 p.p.m.; February 13 to 28, 1.625 p.p.m., and March 1 to 14, 3.25 p.p.m. The total added was about 38 p.p.m. or 0.0608 gram thallium per jar. The zinc, manganese, aluminum, boron, and copper treatments and the first thallium treatment were added in solution and mixed with the soil before it was placed in the jars. Two Turkish tobacco plants per jar were set on December 14. One-half gallon glazed earthenware jars were used.

No frenching or thallium chlorosis had developed in the plants in any of the treatments on the Experiment Station farm soil up to March 7, though 28 p.p.m. of thallium had been added to the thallium-treated jars.

No data on the amount of thallium in soils has come to our attention but Clark and Washington (1) have estimated that the amount in the 10-mile crust (hydrosphere and lithosphere) is less than 1 part of thallium per billion. Seemingly the amount added in the soil culture experiments is much greater than that ever present in soils. The plants were nitrogen deficient and budding out at this time. They averaged 30 inches in height and the plants in the thallium-treated jars had made fully as much growth as the others.

The plants were cut back and suckers allowed to grow, growth being good except in the thallium-treated jars. These plants made only about one-third as much growth as the others, and the leaves during early growth were entirely yellow, distorted, and strapped, but not frenched. Three of these plants died, while one developed a normal growing point but a marginal spotting appeared in the older leaves, apparently due to thallium. The other thallium-treated plants remained severely chlorotic, but with no indication of frenching. The plants in the other treatments were 12 inches high at the close of the experiment. They had both nitrogen and potash deficiency symptoms but there were no indications of frenching.

The plants in the Mayfield soil showed symptoms of phosphorus deficiency by January 8. Phosphate additions (0.4 gram $CaH_4(PO_4)_2.H_2O$) were made to one jar in each treatment on February 5 and again on March 7. Nitrogen deficiency developed later. The plants in all jars frenched, but those in the jars receiving phosphate frenched later and less severely than the others. Thallium toxicity did not develop in any of the plants, and on the whole the plants in the thallium-treated jars frenched later than the others and no more severely. The plants were removed on April 8 after having made fair-sized growth. None of the treatments affected growth materially. The soils were removed from each jar and after nitrogen, phosphorus, and potassium additions had been made, were returned to the jar. Two Turkish tobacco plants then were set in each jar. Except in the thallium-treated jars, they made good growth, and by July 14 were, on the average, 36 inches high. Some nitrogen deficiency had developed; however, none of the plants frenched. The plants in the jars which had received a total of 38 p.p.m. of thallium during the growth of the previous crop were entirely yellow within a few days after setting and never recovered from this chlorosis or made any growth though they lived during the entire experiment. (See Fig. 2.)

A second soil culture experiment was made with the Mayfield soil. One Turkish tobacco plant and one hybrid Burley plant (for a purpose not related to this paper) were set in each jar. Thallium was added from February 25 to May 8 to two of the jars, on alternate days, at the rate of 0.065 p.p.m. Chlorosis developed in the Turkish plant in one of the thallium-treated jars on March 18 at which time 7.150 p.p.m. of thallium had been added. It disappeared on April 5 even though thallium additions had continued to bring the total at this

time to 11.05 p.p.m. The thallium-treated plants were stunted, being only about one-third the size of the other plants. All the plants frenched but those in the thallium-treated jars later and less severely than the others. Phosphorus and nitrogen deficiency developed during the experiment.

In the latter part of the experiment, in an attempt to recover the plants from frenching, nitrogen additions were made at three different times. In two of the jars, one thallium-treated and one not, sodium nitrate was used, and in the other two jars calcium nitrate. The original growing points in none of the plants recovered from their frenched, rosetted condition. The calcium nitrate-treated plants, however, threw out numerous suckers which made little growth and remained very severely frenched, while the sodium nitrate-treated plants produced two suckers each which, though frenched at first, recovered, made good growth, and never frenched again. This difference in effect of the two nitrogen salts on frenching is mentioned in a previous publication (2).

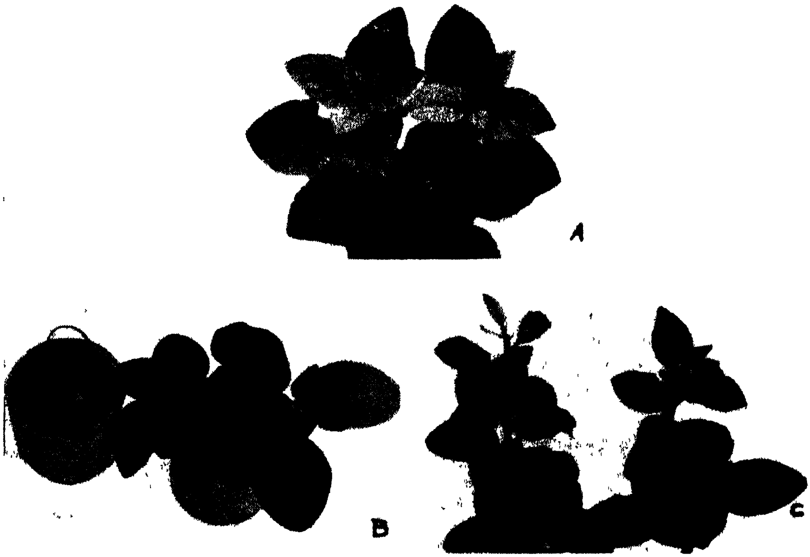

FIG. 2.—Plants grown in soil cultures. A, Turkish tobacco showing moderately severe frenching and severe phosphorus deficiency spotting. Plants grown in Mayfield soil, plot 202, ML, pH 6.75, jar 24 treated with Mn, Zn, B, Cu, and Al. B, Turkish tobacco plants showing the effect of thallium on the second crop of plants in the Mayfield soil. Jar 15 received no thallium. Jar 16 received 38.025 p.p.m. of thallium during the growth of the first crop, with no visible effect on the plants. C, Turkish tobacco grown in the Mayfield soil which had been field treated with manure and limestone (pH 6.75). Plant 2 untreated; plant 3 thallium treated; 13.975 p.p.m. of thallium had been added at the time of frenching. The yellow-vein type of chlorosis appears on a leaf about the center of plant 3. The plants frenched the same day. The plant at the front of each jar is a Burley hybrid.

SUMMARY

Studies at the Kentucky Agricultural Experiment Station have shown that frenching of tobacco is related to the reaction or lime content of the soil and to the soil nutrient supply. More recently, studies have been made with particular reference to the effect of thallium on growth of tobacco plants in water, sand, and soil cultures. Thallium addition caused chlorosis in all three cultures. Additions of 0.04 p.p.m. of thallium produced chlorosis in Turkish tobacco seedlings in water cultures. Larger amounts were required in most sand cultures though 0.035 p.p.m. produced chlorosis in one set. This disappeared, however, even though the thallium additions were continued to give a total of 0.395 p.p.m. Much larger amounts were required in the soil cultures, 7.15 p.p.m. producing temporary chlorosis in one soil culture experiment. In another experiment a total of 28 p.p.m. did not produce chlorosis.

This thallium-induced chlorosis appeared in several forms, but all of these were unlike frenching in several respects. Frenching of the type appearing in the field starts in the interveinal tissue of the apical margin, while the thallium-induced chlorosis appears in the tissue at the base of the leaf and along the larger veins. Thallium-induced chlorosis also may appear first in the larger leaves of the plant, while the first symptom of frenching appears only in the top leaves of the main plant or the suckers.

Thallium treatments did not hasten frenching in soils in which frenching occurs in the field, nor did thallium treatments produce frenching in soils in which frenching does not occur in the field. Liming and a low nutrient content did not increase thallium chlorosis, whereas these conditions do tend to produce frenching.

A much greater amount of thallium was required to cause chlorosis in the soil cultures than presumably is ever present in soils where frenching occurs.

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MICROBIAL ACTIVITY IN RELATION TO SOIL AGGREGATION[1]

T. C. PEELE[2]

THE physical conditions of soils influence their productivity and resistance to erosion. The degree of aggregation of the clay into large water-stable granules has been widely used as an index of the physical properties. Soils in which a high proportion of the silt and clay is in the form of water-stable granules are comparatively permeable to air and water, are relatively resistant to erosion, and provide good media for plant growth. Any procedure which tends to promote aggregation of the finer soil separates may be expected to improve the soil structure and to result in a decrease in erosion. A number of workers have shown that additions of organic matter to soil result in improved physical conditions. Some of the effects on the physical properties attributed to the incorporation of organic matter with soil are increase in aggregation of the silt and clay, increase in infiltration rate, decrease in field volume weight, increase in moisture retention, and decrease in runoff and erosion.

The increase in infiltration rates and the decrease in runoff and erosion are probably due largely to the effect of the organic matter on soil aggregation and to the mulch effect of the portion of the organic matter which remains on the surface of the soil. The mechanism of soil aggregation in all its phases has never been clearly explained. However, from the considerable amount of data available on this subject it appears certain that there are several kinds of binding agents involved in the formation of different types of soil aggregates. These binding agents may be roughly divided into two kinds, inorganic and organic. The aggregation of the B horizon of lateritic soils, such as the Cecil series, furnishes an excellent example of aggregation due to inorganic binding forces. Frequently these soils will contain 50% or more clay and over 95% of the particles may be aggregated into water-stable granules larger than 0.02 mm. The organic matter content is usually less than 1% in the B horizon, and it does not seem likely that this small amount could cause the aggregation observed in these soils.

The organic binding forces may be divided for convenience into two groups. The first group is made up of colloids consisting of the decomposition products of plant residues probably of the lyophobic type and similar to the ones described by Myers (2)[3], most of which are included in dilute alkali extracts of well-decomposed organic matter. The other group consists of the cells of micro-organisms and their secretory products, such as mucus, slime, or gum, produced during growth and resembling lyophilic colloids and gels in their physical state. These growth products of micro-organisms have re-

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[2]Soil Technologist.
[3]Figures in parenthesis refer to "Literature Cited", p. 212.

ceived scant attention as a factor in the formation of soil structure, particularly as a binding agent in the development of water-stable soil aggregates.

The work of Shrikhande (4, 5) showed that there was a large increase in stickyness of straw during its decomposition. Kanivetz and Korneeva (1) reported an increase in percentage of water-stable aggregates in soils infected with Azotobacter and Trichoderma. They found that organic matter in the form of straw when infected with *Trichoderma lignorum* and added to the soil caused a sixfold increase in proportion of water-resisting aggregates.

Waksman and Martin (7) presented data showing a marked increase in percentage of bound material when sand-bentonite mixtures containing sucrose or cellulose were inoculated with pure cultures of bacteria and fungi. They reported that similar results were obtained using sand-clay mixtures. The binding action of the fungi was attributed to the extensive mycelium and the binding action of *Azotobacter indicum* to the slimy substances produced by the organism.

It is the purpose of this paper to present the results of some preliminary studies dealing with the relation of microbial activity to soil structure and showing conclusively that water-stable aggregates can be formed from the mucus produced by bacteria.

MATERIALS AND METHODS

The media used in this investigation are listed below:

Medium 1

Agar	15.0 grams
Peptone	1.0 grams
Dextrose	2.5 grams
KH_2PO_4	0.25 gram
$FeCl_3$	trace
$MgSO_4 \cdot 7H_2O$	trace
Distilled water	1 liter

Reaction adjusted to pH 6.3 using NaOH

Medium 2

Agar	15.0 grams
Dextrose	1.0 grams
Peptone	0.15 gram
Asparagine	0.15 gram
$MgSO_4 \cdot 7H_2O$	0.10 gram
$CaCO_3$	0.10 gram
KH_2PO_4	0.10 gram
$FeCl_3$	trace
Distilled water	1 liter

Reaction adjusted to pH 6.6 using NaOH

Medium 3

Peptone-glucose acid agar (6)

Agar	25.0 grams
KH_2PO_4	1.0 grams
$MgSO_4 \cdot 7H_2O$	0.5 gram
Peptone	5.0 grams
Glucose	10.0 grams
Water	1 liter

Reaction adjusted to pH 3.8 to 4.0 using sulfuric acid

The procedure used in making aggregate analyses was similar to that previously reported (3) with the exception that a wet-sieving operation has been included in order to obtain a measure of the coarser aggregates. The results obtained from aggregate analysis are influenced considerably by the procedure used in making the determinations, and until some uniform procedure is adopted by different laboratories for making these analyses, it is highly desirable that the exact procedure used be given by each investigator in reporting the results of his work.

In the present investigation the soil was allowed to become air-dry and a moisture determination made the day preceding analysis. Soil aggregates or lumps larger than 2 mm in diameter were used in the analysis. Fifty grams (oven-dry basis) of the air-dry soil were placed in a 600-ml beaker and wetted with 400 ml of distilled water. The soil was allowed to slake for 3 hours and transferred by means of a wash bottle to a 2-mm sieve 5 inches in diameter resting in a small container with the bottom of the sieve covered by about ½ inch of distilled water. The sieve was moved gently up and down in the water until all soil particles less than 2 mm in diameter had passed through it. The soil on the sieve was transferred to a tared beaker, oven-dried, and weighed. The soil suspension containing particles less than 2 mm in diameter was transferred to a 1-liter graduated cylinder and the volume made up to 1 liter using distilled water. The cylinder was shaken end over end and the temperature recorded. It was then shaken end over end five times, placed upright on a level surface, and hydrometer readings, using a Bouyoucos hydrometer, were made at appropriate intervals to obtain the amount of soil in suspension having diameters of 0.05 and 0.02 mm or less. The settling times at which the readings were made are taken from Table 1. The values in this table were calculated by the procedure previously outlined (3). The hydrometer readings must be corrected by adding 0.2 gram for each degree Fahrenheit above 67 or subtracting this amount for each degree the temperature of the soil suspension is below this figure when the hydrometer readings are made.

TABLE 1.—*Aggregate analysis by the hydrometer method.*

Particle size, mm.	Sedimentation time for hydrometer readings	
	Temperature 17.5° to 22.5° C	Temperature 22.5° to 27.5° C
0.05	45 sec.	38 sec.
0.04	1 min., 10 sec.	1 min., 0 sec.
0.03	2 min., 0 sec.	1 min., 50 sec.
0.02	4 min., 35 sec.	4 min., 0 sec.
0.01	18 min., 15 sec.	16 min., 10 sec.

In calculating the percentage of soil in aggregates of the different sizes the fraction above 2.0 mm in size is obtained from the oven-dry weight of soil retained by the sieve. The fraction 0.05 to 0.02 mm in diameter and the one less than 0.02 mm in diameter are obtained from the corrected hydrometer readings. The corrected reading for particles 0.02 mm in size is subtracted from the corrected reading for particles 0.05 mm in size in order to obtain the fraction having diameters of 0.05 to 0.02 mm. The soil fraction having diameters of 2.0 to 0.05 mm is obtained by the difference between the weight of the other fractions and the oven-dry weight of the original sample. All aggregate analyses reported are averages of duplicate determinations.

EXPERIMENTAL RESULTS

A number of cultures of rod-shaped bacteria were isolated from Cecil clay loam. One of these cultures (No. 21) was used in testing the effect of bacterial mucus on soil aggregation. The organism is a large, aerobic, spore-forming rod and produces viscous mucus on solid media. The bacteria were grown on slopes of medium 1 for a period of about 3 days, which was sufficient for the production of abundant growth on the surface of the agar, the growth consisting of the living cells of the bacteria plus the mucus or slime produced during growth. Portions of the mucus were removed from the surface of the medium and incorporated with air-dry soil (Cecil clay) which had previously been passed through a 1-mm sieve. The soil and mucus were kneaded together and shaped in the form of small, round granules about ¼ inch in diameter. The granules were then allowed to become air-dry. Similar granules were made using the same soil and using distilled water instead of the bacterial mucus.

The air-dry granules made with mucus and those made with water were placed in distilled water and allowed to slake. The granules made with bacterial mucus were very stable and did not disintegrate even after continuous soaking for 24 hours. The granules made with distilled water disintegrated completely in one minute or less. Fig. 1 shows a Cecil clay granule bound by slime of culture 21 grown on medium 1. The air-dry granule was placed in distilled water and had been soaking for 40 minutes when the photograph was made with the granule still immersed in water. Fig. 2 shows the same granule after soaking for 24 hours. There was no visible slaking after soaking for 24 hours. It is evident that the granules bound with the mucus of bacteria were water-stable. This binding action is not a specific property of the bacterial specie reported but appears to be a general property of all bacteria which produce considerable quantities of mucus. A number of different species have been tested and in every case it was possible to produce water-stable aggregates from their mucus, although the degree of stability of the aggregates varied widely with different species and appeared to be associated with the viscosity of the mucus.

The binding action of the mucus seems to be due largely to the cohesiveness of the mucus for soil and to the fact that the colloidal mucus reacts irreversibly on dehydration as a result of becoming air-dry or, if not entirely irreversible, the hydration after air-drying

proceeds extremely slowly. The binding action of the mucus is not only effective with the inorganic colloidal soil material but also binds the coarser separates, such as sand.

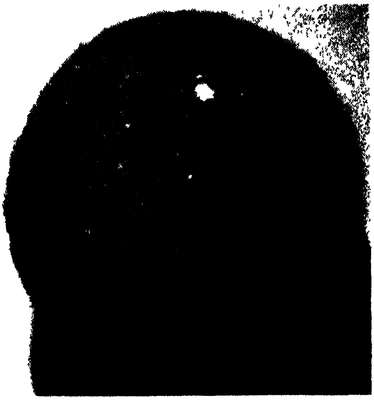

FIG. 1.—Granule of Cecil clay bound by mucus of bacterial culture No. 21, photographed in water after soaking for 40 minutes. Actual diameter of granule was ¼ inch.

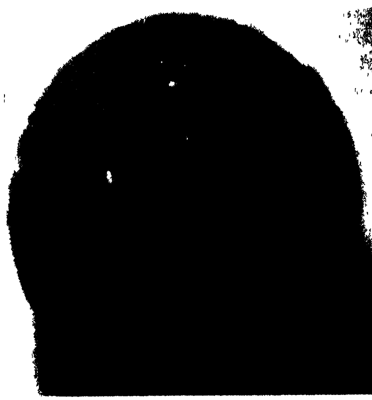

FIG. 2.—Granule of Cecil clay bound by mucus of bacterial culture No. 21 photographed after soaking in distilled water for 24 hours. Note lack of slaking.

The mucus from an agar culture of Austrian field pea nodule bacteria was mixed with white quartz sand having diameters of approximately 0.20 mm. The sand and mucus were kneaded together and shaped into a small granule. A similar granule was made using only distilled water. Both granules were allowed to become air-dry. The granule made with mucus retained its shape, but the one made with distilled water only disintegrated completely on drying as would naturally be expected since there was no binding agent present. The granule containing mucus was placed in distilled water and allowed to soak for 30 minutes. There was no evidence whatever of disintegration as a result of this soaking. Fig. 3 shows the quartz bound with mucus after soaking for 30 minutes, and Fig. 4 shows quartz grains of the size used in making the granule, the magnification being the same in each case.

FIG. 3.—White quartz granule bound with mucus of Austrian field pea nodule bacteria. Photographed after the air-dry granule had soaked for 30 minutes in distilled water. Note lack of disintegration. Actual diameter of granule approximately ¼ inch.

The evidence shows that water-stable granules can be easily pro-

duced under artificial conditions by incorporating bacterial mucus with soil. In order to determine the effect on aggregation of micro-organisms growing directly in the soil, an experiment was conducted in which the activity of the soil micro-organisms was markedly increased by the addition of a readily available source of energy to unsterile soil. A sugar (sucrose) was selected as the energy source chiefly for two reasons. First, it was known that the sucrose would cause a large increase in growth of soil bacteria and fungi, and second it would, to a large extent, be broken down completely to carbon dioxide and water and would not leave appreciable quantities of

FIG. 4.—White quartz grains of the size used in making the granule shown in Fig. 3. Actual diameter of quartz grains approximately 0.2 mm.

organic residues, other than secretory products and cellular material of micro-organisms, which might serve as binding agents and complicate the interpretation of the results.

The A horizon of a lateritic soil (Cecil sandy loam) was collected from the South Carolina Agricultural Experiment Station farm. The soil was air-dried, passed through a 1-mm sieve, and thoroughly mixed. Aliquot portions of 800 grams each were placed in small, glazed containers. The treatments received by different containers, together with the results obtained, are shown in Table 2. Sucrose applications were at the rate of 16 tons per acre based on 2,000,000 pounds oven-dry soil per acre. On the same basis, nitrogen, phosphorus, and potassium applications were made at the rate of 500 pounds each and calcium carbonate at 2 tons per acre. The sucrose and calcium carbonate were incorporated with the soil dry and the other treatments were added in solution. The moisture content of the soil was raised to 5% above the moisture-equivalent at the beginning

TABLE 2.—*Effect of microbial activity on soil aggregation.*

Treatments*	Incubation time	Bacteria in soil at end of incubation, millions per gram	Fungi in soil at end of incubation, millions per gram	Percentage of different size aggregates			
				Above 2.0 mm.	2.0–0.05 mm.	0.05–0.02 mm.	Below 0.02 mm.
Sucrose	None†	‡	‡	0	65.7	11.0	23.3
N-P-K	1 day	‡	‡	0	72.2	12.5	15.3
Sucrose + N-P-K	1 day	‡	‡	62.0	26.5	4.9	6.6
Sucrose + N-P-K + $CaCO_3$	1 day	‡	‡	23.5	56.0	9.5	11.0
None	18 days	9.83	0.04	0	76.6	10.8	12.6
N-P-K	18 days	9.97	0.04	0	74.2	12.0	13.8
Sucrose + N-P-K	18 days	465.00	5.37	57.7	33.7	4.0	4.6
Sucrose + N-P-K + $CaCO_3$	18 days	367.00	0.82	54.5	37.6	3.5	4.4

*N, P, K (nitrogen, phosphorus, and potassium) applied at rate of 0.025 gram each per 100 grams soil. Sucrose applied at rate of 1.6 grams and $CaCO_3$ 0.2 gram per 100 grams soil on oven-dry basis.

†Soil wetted and dried immediately.

‡No bacteria or fungi counts were made on the soils incubated less than 18 days.

and at intervals of 3 or 4 days during the incubation period. Some of the cultures were incubated for 18 days and some for 1 day. In one case sucrose-treated soil was wetted and allowed to air-dry immediately in order to determine whether the sucrose had any effect on aggregation when no incubation time was allowed for the microorganisms to develop. Numbers of bacteria and fungi present in the soil were determined by the plate method at the end of the 18-day incubation period and were determined only in soil cultures which were incubated for this length of time. The bacterial counts were made using medium 2 and the fungi counts using medium 3. Aggregate analysis was made on all soils immediately after the end of the incubation periods and was preceded by air-drying in each case.

The results in Table 2 show that the addition of sucrose caused a marked increase in the percentage of water-stable aggregates larger than 2 mm. This effect on aggregation occurred only when an incubation period permitting the development of the micro-organisms ensued after the sucrose was added to the soil. When the sucrose was added and the soil dried immediately, thus preventing the growth of the micro-organisms, there was no increase in aggregation of the soil. Mineral nutrients appeared to have little effect on the numbers of bacteria and fungi present in the soil, with the exception of calcium carbonate which depressed the growth of the fungi and to some extent the numbers of bacteria present. Nitrogen, phosphorus, and potassium did not have any appreciable effect on aggregation. The sucrose plus calcium carbonate treated soil was somewhat less strongly aggregated at the end of 1 day's incubation than the soil receiving sucrose without calcium carbonate. The soil treated with sucrose plus

nitrogen, phosphorus, and potassium but without calcium carbonate, when incubated for 1 day only, contained a slightly higher percentage of aggregates above 2.0 mm in diameter than did a similarly treated soil incubated for 18 days. However, it is doubtful whether this slight difference is significant, and it may be noted that the sucrose-treated soil incubated for 18 days had a higher percentage of aggregates larger than 0.05 mm in diameter than did the soil incubated only 1 day.

After finding that water-stable soil aggregates could be produced by stimulating the growth of the natural soil population through the addition of sugar, it was thought desirable to study this process under aseptic conditions using pure cultures of bacteria and fungi. Portions of the original soil sample collected for the preceding experiment, which had been air-dried and passed through a 1-mm sieve, were placed in 1-liter flasks, plugged with cotton, and sterilized in an autoclave at 15 pounds pressure for 3 hours. Sucrose solution and distilled water containing 0.05% $NaNO_3$ and 0.05% KH_2PO_4 were sterilized separately at 15 pounds pressure for 20 minutes. The sucrose solution and sterile water containing the mineral nutrients were added to the flasks in the desired amounts after the sterile soil had cooled. Inoculations of fungi and bacteria were made by means of water suspensions of the organisms. The flasks were all incubated for 12 days, then the soil was removed, rapidly air-dried, and its degree of aggregation determined. The treatments and results obtained are shown in Table 3.

TABLE 3.—*Effect of microbial activity on soil aggregation.**

Treatments	Percentage of different size aggregates			
	Larger than 2 mm.	2 to 0.05 mm.	0.05 to 0.02 mm.	Less than 0.02 mm.
Sterile soil, no treatment........	0	71.0	12.5	16.5
Sterile soil plus sucrose.........	0	72.5	9.5	18.0
Sterile soil plus sucrose inoculated with *C. blakesleeana*.....	79.0	11.3	2.5	7.2
Sterile soil plus sucrose inoculated with bacterial culture 7..	6.5	72.2	10.8	10.5
Sterile soil plus sucrose plus fresh soil suspension..............	14.4	68.4	8.5	8.7

*Date reported are averages of duplicate treatments.

The data in Table 3 show that a marked increase in aggregation occurred when sterile soil containing sucrose was inoculated with cultures of bacteria or fungi and incubated for a sufficient time to permit good development of micro-organisms. When sterile soil containing sucrose was incubated, the sugar had no effect on aggregation. The fungous culture was much more effective than the bacterial culture or the mixed culture represented by the fresh soil suspension inoculation in promoting the formation of water-stable aggregates. This indicates a possibility that it may be plausible to inoculate with a suitable fungous culture areas where green manure is being incorporated

with soil and where it is desired to increase the degree of aggregation. However, a decision on that point must await further investigation. Preliminary tests have indicated that there is a large variation in the effect of different species of bacteria on soil aggregation, and it is probable that some bacteria are more effective than some species of fungi in causing the formation of water-stable granules.

SUMMARY

The mucus produced by bacteria was found to be an effective binding agent in the formation of water-stable soil granules. Bacterial mucus from Austrian field pea nodule bacteria and various other bacterial species grown on artificial media produced water-stable aggregates when incorporated with soil. This was true whether the soil contained a large amount of clay or consisted entirely of quartz sand.

The addition of sucrose to soil containing bacteria or fungi and followed by an incubation period caused a marked increase in percentage of large water-stable granules. When sucrose was incorporated with soil under sterile conditions and the soil maintained free of micro-organisms, it had no effect on aggregation.

A fungous culture was much more effective than a bacterial culture in producing water-stable granules under aseptic conditions, but it is probable that this relationship varies with different species of both kinds of organisms.

The activities of micro-organisms appear to be of much greater importance in connection with soil structure than their consideration in the past would indicate.

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EFFECT OF POLLINATION UPON CHEMICAL COMPOSITION OF SILKS OF CERTAIN INBRED LINES OF MAIZE[1]

IRWIN R. HOENER AND RALPH O. SNELLING[2]

IN a study of the chemical composition of developing ears of maize and of the influence of composition upon the resistance of certain strains to the corn earworm (*Heliothis obsoleta*, Fab.), data have been obtained relative to the effect of pollination on the composition of the silks.[3]

The pollination of maize silks has an immediate retarding effect upon their development, while unpollinated silks will continue to increase in length and total volume. If pollination were prevented, therefore, it would result in a much larger volume of silks for analysis. While prevention of pollination would facilitate the technic in providing sufficiently large samples, it was not known whether the composition of silks grown under such conditions would be comparable with that of silks on which the corn earworms normally feed. The data reported here indicate the effect of pollination on protein and moisture content of the silks, and on the H-ion concentration and the refractive index of the juice expressed from them.

MATERIALS AND METHODS

Inbred lines Kansas K4, Iowa L317, Ohio 51, and U. S. 540, grown at Urbana, Illinois, in 1938 were used in this study. Silks from four rows of each inbred were analyzed. In two alternate rows pollination was prevented by covering the young shoots with parchment bags before the silks had emerged. The remaining two rows of each inbred were left without bags to be normally pollinated. Approximately 100 plants were represented in each of the samples.

SAMPLING AND PREPARATION FOR ANALYSES

The silks of inbred 51 were sampled July 30; 540 and K4 on August 5, and L317 on August 12, 1938. These samples were taken approximately 72 hours after emergence, which was before any outward appearance of drying was evident. The shoot bags were removed from the unpollinated silks about four o'clock in the afternoon the day before the samples were taken. This should have enabled any moisture differences, due to the bags, to become adjusted, and it is believed that very few silks were pollinated during this period of exposure, although it is realized that some pollen often is shed late in the afternoon. The samples were taken the next morning before significant amounts of pollen had been released.

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[3]The writers wish to express their sincere appreciation to Dr. E. E. DeTurk for his advice and to Mr. C. H. Shannon for his help in making some of the analyses. The cooperation of Mr. R. A. Blanchard is acknowledged in connection with the project on the causes of corn earworm resistance.

The silks were removed from the shoots by cutting just at the tip of the developing husks. They were immediately cut fine and mixed in a Hobart salad cutter. The juice for H-ion concentration and refractive index determinations was expressed at once from a portion of the cut sample at approximately 2,000 pounds pressure to the square inch. The juice was relatively free of solid material and was not centrifuged before making these analyses. A portion of the mixed sample was dried for the moisture and the protein determinations.[4]

ANALYTICAL METHODS

Moisture.—Moisture was determined by drying a portion of the original sample at 85° C in an electric vacuum oven under a pressure of 100 mm mercury.

Total nitrogen.—Total nitrogen was determined on a portion of the dried silks by the official Kjeldahl-Gunning-Arnold method.

H-ion concentration.—H-ion concentration was determined by the Beckman pH meter and expressed as pH values.

Refractive index.—The refractive index was determined by use of an Abbé refractometer.

DISCUSSION OF RESULTS

Moisture.—In each of the four inbred lines the percentage of moisture was less in the pollinated than in the unpollinated silks. Removal of the shoot bags approximately 17 hours previous to sampling should have permitted the silks to become adjusted from any influence of the bags. The most plausible explanation for this difference is that incipient drying of the silks occurred very soon after pollination even though outwardly the pollinated silks appeared to be as fresh and succulent as those unpollinated. The moisture content of the L317 silks was higher than that of the other inbreds. This may be partially due to conditions at the time of sampling. The sample of L317 silks was taken later than the other samples because of the slightly later silking date of this inbred.

Protein.—The silks from the four inbred lines of corn differed only slightly in the percentage of protein with the exception of L317 which was about 50% higher than the other three. In each inbred, however, the percentage of protein was higher in the pollinated than in the unpollinated silks. As shown in Table 1, the protein content of pollinated silks from inbreds L317 and 540 had more than 1% more protein than the unpollinated silks. The difference in protein in favor of pollinated silks was only 0.44% in inbred 51. No explanation is offered for the considerably higher protein content in silks from L317 except that it is possibly a genetic difference. It is not believed that the difference in time of silking is responsible for its higher protein content as was suggested in regard to its high moisture.

H-ion concentration.—The pH values of the expressed juice of both the pollinated and the unpollinated silks of L317 were slightly higher than those of the other strains. In inbreds K4 and L317 there was no significant change in the H-ion concentration of the juice because of pollination, while in inbred 51 there was an increase of 0.12 pH in the

[4]The term "protein" refers to the total nitrogen multiplied by the conventional factor 6.25.

TABLE 1.—*Protein and moisture content of pollinated and unpollinated silks and H-ion concentration and refractive index of the juice expressed from them for inbred lines Kansas K4, Iowa L317, Ohio 51, and U. S. 540, Urbana, Illinois, 1938.*

Condition of silks	Inbred K4	Inbred L317	Inbred 51	Inbred 540
		Percentage Protein*		
Unpollinated.........	13.97	20.97	14.72	14.13
Pollinated............	15.00	22.07	15.16	15.22
Difference..........	+ 1.03	+ 1.10	+ 0.44	+ 1.09
		Percentage Moisture		
Unpollinated.........	89.29	91.82	88.68	89.86
Pollinated.	89.06	91.33	87.10	89.02
Difference..........	− 0.23	− 0.49	− 1.58	− 0.84
		H-ion Concentration of the Juice		
Unpollinated.........	5.13	5.43	5.12	5.18
Pollinated............	5.10	5.41	5.24	4.75
Difference..........	− 0.03	− 0.02	+ 0.12	− 0.43
Unpollinated.........	1.3420	1.3440	1.3450	1.3422
Pollinated............	1.3435	1.3440	1.3469	1.3425
Difference..........	+ 0.0015	0.0	+ 0.0019	+ 0.0003

*Water-free basis.

juice from pollinated silks in contrast to a decrease of 0.43 pH in the juice from pollinated silks of inbred 540.

Refractive index.—The refractive index of the juice from both pollinated and unpollinated silks of inbred 51 was slightly higher than that of the other inbreds. However, the refractive index of the juice was not markedly influenced by pollination.

SUMMARY

Pollinated and unpollinated silks of four inbred lines of maize were studied as to their protein and moisture content, the H-ion concentration, and the refractive index of their expressed juice approximately 72 hours after emergence.

The pollinated silks of the four inbred lines appeared to be significantly higher in protein content and significantly lower in moisture content than the unpollinated silks. The protein content of the silks of the inbred line L317 was considerably higher than that of the other three inbred lines.

The H-ion concentration of the juice expressed from the silks of K4 and L317 was not influenced by pollination; while that of inbred 51 showed an increase of 0.12 pH and that of inbred 540 a decrease of 0.43 pH apparently as a result of pollination.

Pollination did not appear to influence significantly the refractive index of the juice expressed from the silks.

THE INFLUENCE OF GRAZING UPON CERTAIN SOIL AND CLIMATIC CONDITIONS IN FARM WOODLANDS[1]

ROBERT F. CHANDLER, JR.[2]

IT is widely recognized that the grazing of farm woodlands in the eastern United States is an undesirable practice. Observations as well as experimental data show that intense grazing utlimately results in the destruction of all forest-tree reproduction, as well as considerable crown injury and decreased growth rate in the overstory (1, 8, 9, 10).[3]

Many factors have been suggested as being responsible for the general decrease in growth and vigor of the trees. Some of the suggested causes are compaction of the surface soil when trampled by cattle, disintegration and loss of litter due to excessive drying and to having been blown away, and lack of available soil moisture. Adequate experimental data indicating the extent to which grazing has influenced these conditions seem to be lacking in the literature. It is the purpose of this paper to present some actual measurements of certain soil and climatic conditions in 18 grazed and an equal number of ungrazed farm woodland areas in central New York. The factors studied are listed as follows: Hydrogen-ion concentration (pH), organic matter content, volume weight, moisture equivalent, moisture content, degree of aggregation of soil particles, soil temperature, air temperature, light intensity and relative humidity.

MATERIALS AND METHODS

The various woodland areas were so selected that a grazed and ungrazed area could be studied on the same soil type. Many times only a fence separated the two areas, and in no case was the distance between the compared grazed and ungrazed areas more than ½ mile. The climatic data were obtained from both areas within a period of less than 1 hour.

The ungrazed woodlands consisted of fully-stocked second-growth hardwood stands, the dominant trees of which exceeded 60 years of age. The soils were virgin in that they had never been cultivated or pastured. The stands on the grazed areas were of similar species composition and age, except that reproduction and all younger-aged trees were missing. The stage of grazing corresponded to the open park and final stages as defined by Day and DenUyl (8). The original humus layer had disappeared, and a grass cover was essentially the only ground vegetation on the areas. Fig. 1 shows representative grazed and ungrazed woodlands on the same soil type. Differences of this order occurred between all paired comparisons.

Statements concerning the location, soil type, humus-layer type (12), and principal forest tree species present on the various grazed and ungrazed areas are presented in Table 1. In order to conserve space, the experimental area numbers are also presented, and are used for identification purposes in subsequent tables.

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[1]Contribution from Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication December 26, 1939.

[2]Research Assistant Professor of Forest Soils.

[3]Figures in parenthesis refer to "Literature Cited", p. 230.

In order to determine the volume weight soil samples were collected according to the method of Burger (4), being obtained by driving a steel cylinder of 1,000-cc

FIG. 1.—Photographs of typical paired woodland areas on Lordstown silt loam soil. A, grazed; B, ungrazed.

volume into the soil. All areas were sampled in duplicate. The samples were carefully transferred to 1 gallon waterproof cardboard containers. After being transported to the laboratory the samples were weighed, dried, and reweighed to obtain

TABLE 1.—*Soil type, humus-layer type, and principal forest tree species on the various experimental plots on the grazed and ungrazed woodlands.*

Experimental area No.	New York state county in which located	Soil type	Humus layer type	Principal forest trees present	
				Grazed	Ungrazed
I	Cayuga	Ontario loam	Coarse mull	Sugar maple, basswood, Americam elm	Sugar maple, basswood, American elm
II	Wayne	Ontario loam	Coarse mull	Sugar maple, basswood	Sugar maple, basswood
III	Wayne	Ontario loam	Coarse mull	Sugar maple	Sugar maple, basswood, white ash
IV	Ontario	Ontario loam	Coarse mull	Sugar maple, red oak, basswood	Sugar maple, red oak, basswood
V	Wayne	Ontario loam	Coarse mull	Sugar maple, shagbark hickory	Basswood, sugar maple, beech
VI	Wayne	Ontario loam	Coarse mull	Sugar maple, basswood, beech	Sugar maple, basswood, beech
VII	Tompkins	Lansing silt loam	Coarse mull	Sugar maple	Sugar maple, basswood, white ash
VIII	Ontario	Dunkirk silt loam	Coarse mull	Sugar maple, beech, basswood	Sugar maple, beech, basswood
IX	Onondaga	Honeoye silt loam	Coarse mull	Beech, sugar maple, basswood	Beech, sugar maple, basswood
X	Onondaga	Honeoye silt loam	Coarse mull	Sugar maple, American elm, basswood	Sugar maple, American elm, basswood
XI	Tompkins	Volusia silt loam	Coarse mull	Red oak, shagbark hickory, sugar maple	Red oak, shagbark hickory, sugar maple
XII	Tompkins	Volusia silt loam	Coarse mull	Shagbark hickory, red maple, red oak	Shagbark hickory, red maple, red oak
XIII	Cortland	Volusia silt loam	Coarse mull	Sugar maple, white ash, black cherry	Sugar maple, white ash, black cherry
XIV	Tompkins	Lordstown stony silt loam	Thin coarse mull	Red oak, white oak, chestnut oak	Red oak, white oak, sugar maple
XV	Cortland	Chenango gravelly silt loam	Fine mull	Sugar maple, beech	Sugar maple, beech
XVI	Cortland	Lordstown stony silt loam	Granular mor	Sugar maple	Beech, sugar maple
XVII	Cortland	Lordstown silt loam	Root mor	Sugar maple	Sugar maple
XVIII	Tompkins	Lordstown stony silt loam	Root mor	Red oak, chestnut oak, red maple	Red oak, red maple

an estimate of the moisture content at time of sampling. The volume weight was calculated from the dry weight of the sample. Because of the nature of the subsequent determinations to be made on the sample, the above drying took place at a temperature of 60° C instead of the customary 105° C.

The samples were next mixed somewhat with the hands, so as to increase the uniformity. Every effort was made to preserve the aggregates. Representative sub-samples were then transferred to 250 ml beakers and aggregate analysis made in a manner similar to that described by Tiulin (18), with the exception that instead of directing a gentle stream of water onto the soil in the sieves, each sieve was dipped in and out of a basin of water 60 times, and the aggregates remaining on a given sieve were considered as water stable. The size distribution of all particles less than 0.02 mm in diameter was determined by the pipette method. The same soil sample which was passed through the sieves was returned to a beaker and treated with sodium carbonate solution, vigorously stirred with an electric mixer for 10 minutes, and again passed through the sieves to determine the size distribution of the ultimate particles.

Other sub-samples were removed, passed through a 20-mesh sieve, and used for the determination of pH, moisture equivalent, and organic matter content.

The pH was determined potentiometrically, using a glass electrode.

The moisture equivalent determination was made in the usual manner by determining the moisture content of the wet samples after they were subjected to a centrifugal force of 1,000 times gravity for 30 minutes.

A small portion of the soil was ground in an agate mortar to pass a 100-mesh sieve. The organic matter content was estimated according to the modification of the Degtjareff method as proposed by Wakley and Black (20) and as used by Browning (3).

A Taylor humidiguide was used for the determination of air temperature and relative humidity. The measurements were made at about 1 foot from the ground surface.

Soil temperatures were taken with a laboratory thermometer at a depth of 1 inch.

An estimate of the relative size distribution of pores was made on certain soils by the method proposed by Bradfield and Jamison (2).

Light intensity was measured with a Weston sunlight meter. A sheet of white typewriting paper was placed on the ground and the photronic cell was held at a distance of 1 foot, directly above the center of the paper. The reflected light was measured at 20 different spots, about 10 feet apart. Measurement of the intensity of reflected full sunlight was made in the open and all results expressed as percentages of these values. On clear days when the intensity of direct sunlight was about 10,000 foot candles, the reflected light intensity was about 2,200 foot candles.

EXPERIMENTAL RESULTS

In Table 2 are presented the data on the hydrogen-ion concentration, organic matter content, volume weight, moisture equivalent, moisture content at time of sampling, and relative wetness. Since the arrangement of the plats was such as to permit paired comparisons, Student's Z method (14) was used to determine statistical significance of the differences between means. For each condition studied, the mean, the difference between means, and the odds against a difference as great as that occurring due to chance alone, are given.

TABLE 2.—*Hydrogen-ion concentration (pH), organic matter content, volume weight, moisture equivalent, moisture content at time of sampling, and relative wetness of surface soil from grazed and ungrazed farm woodlands.*

Experimental area No.	pH		Organic matter, %		Volume weight		Moisture equivalent, %		Moisture content at sampling time, percentage oven dry weight		Relative wetness	
	Grazed	Un-grazed	Grazed	Un-grazed	Grazed	Un-grazed	Grazed	Un-grazed	Grazed	Un-grazed	Grazed	Un-grazed
I	6.57	6.55	5.59	9.41	1.24	1.01	27.3	33.2	8.2	11.7	20.5	28.4
II	7.07	7.23	2.25	6.50	1.32	1.02	13.5	28.1	8.2	10.9	16.7	23.1
III	5.13	6.98	8.05	7.65	1.03	0.85	25.5	30.1	14.6	22.4	31.6	25.4
IV	6.66	5.98	5.72	6.03	1.17	0.96	24.6	25.6	8.7	13.4	23.3	23.5
V	6.20	5.53	7.73	11.50	1.18	0.89	33.1	37.2	6.1	8.2	23.4	31.0
VI	6.13	6.83	7.48	4.76	1.18	0.95	22.3	20.7	6.2	6.9	33.5	23.0
VII	4.84	6.94	3.33	10.76	1.15	0.89	25.3	41.9	7.4	23.3	13.1	25.7
VIII	6.45	6.33	4.83	8.56	1.21	0.77	29.8	37.6	11.2	16.3	16.2	22.7
IX	6.26	6.94	5.68	7.26	1.08	0.96	27.3	35.1	16.1	21.1	20.7	20.6
X	6.61	5.93	8.17	8.48	1.16	0.99	33.6	41.2	9.3	10.3	24.3	20.5
XI	5.55	5.58	5.50	7.60	1.32	0.86	29.7	34.4	11.2	18.7	18.5	22.1
XII	4.86	4.76	4.57	4.65	1.22	1.11	38.1	43.3	5.2	6.3	12.0	10.7
XIII	4.79	4.30	8.79	13.95	1.00	0.78	46.4	51.2	10.7	14.2	18.9	27.3
XIV	6.27	4.32	9.03	11.35	1.14	0.88	42.2	51.8	10.7	9.6	21.4	21.9
XV	4.66	4.39	7.88	7.91	1.00	0.87	34.8	35.6	19.1	26.3	22.5	22.2
XVI	5.42	4.77	4.16	8.86	1.24	1.10	28.0	33.7	10.2	11.6	14.9	26.2
XVII	4.60	4.57	11.26	11.39	0.82	0.79	58.9	46.6	23.0	20.0	19.1	24.4
XVIII	4.35	4.12	5.15	6.38	1.32	0.89	35.9	35.6	4.1	7.2	14.3	17.9
Mean	5.69	5.67	6.40	8.50	1.15	0.92	32.0	36.8	10.6	14.4	20.3	26.1
Odds that difference is not due to chance alone	1:1		499:1		Infinite		216:1		832:1		31:1	

No important difference in pH occurred between the grazed and ungrazed soil, the averages being 5.69 and 5.67, respectively.

The organic matter content of the soil from the ungrazed woodland was significantly higher than that of the grazed areas. There are only two instances where the organic matter content of the grazed area exceeded that of the ungrazed, both occurring on Ontario loam in Wayne County.

The volume weight of the grazed soils was significantly higher than that of the ungrazed. The differences were not great, however, the means being 1.15 for the grazed and 0.92 for the ungrazed.

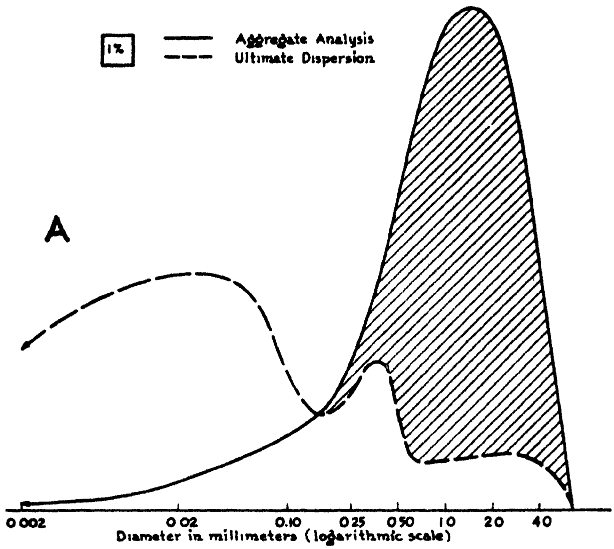
The moisture equivalent was higher in the case of the ungrazed soils. An examination of the individual figures indicates that this difference seems to be largely associated with the organic matter content. The finer textured soils, however, did exhibit higher values for the moisture equivalent.

The moisture content at time of sampling was higher in the ungrazed soils. Since it has been shown by Coile (6) that the organic matter content of soils influences the moisture equivalent considerably more than the wilting percentage, and since Veihmeyer (19) has shown a good correlation between the moisture equivalent and field capacity of soils, expressing the moisture content as relative wetness (percentage of the moisture equivalent) would seem more logical. The last column in Table 2 presents these figures. The mean difference between the grazed and the ungrazed soils is statistically significant.

As previously stated, aggregate and ultimate dispersion analyses were run on all samples. The data for the Ontario loams, Honeoye loams, Volusia silt loams, and Lordstown silt loams are presented graphically by area curves in Figs. 2, 3, 4, and 5.

The experimental area numbers constituting the data are as follows: Ontario loam, Nos. I, II, IV, V, and VI; Honeoye silt loam, Nos. IX, and X; Volusia silt loam, Nos. XI, XII, and XIII; and Lordstown silt loam, Nos. XVI, XVII, and XVIII. The values obtained for No. III were not included in the Ontario loam data because the grazed sample was sifted by mistake before analysis. Number XIV was not used in constructing the curve for the Lordstown soils because it had a thin coarse mull humus layer. It seemed desirable to include only mor humus layers with the Lordstown soils since it is the typical condition for this series. The data from the remaining soil types are not presented because the trends were similar to those shown.

The differences in state of aggregation were not as great as had been anticipated by observation. The soils from the ungrazed woodlands, however, were found to have a larger percentage of aggregates greater than 1 mm in diameter. In order to show these differences more clearly, the area of the curve to the right of a line drawn through the 1-mm point was measured with a planimeter. Since all curves were drawn to the same scale, these figures would represent the relative percentage of the aggregates greater than 1 mm in diameter. The same procedure was also carried out for the entire cross-hatched areas. The data are presented in Table 3.



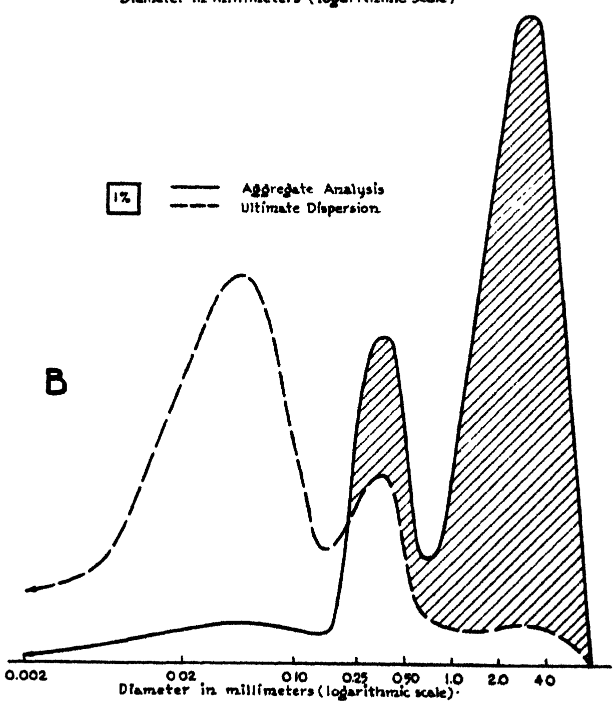


FIG. 2.—Average particle size distribution (area type of curve) for the Honeoye silt loam soils, with and without dispersion. A, grazed; B, ungrazed.

TABLE 3.—*Relative amount of aggregates greater than 1 mm in diameter.**

Soil type	Relative amount of aggregates greater than 1 mm in diameter		Percentage decrease of grazed as compared with ungrazed	Relative amount of aggregates (all size classes)	
	Grazed	Ungrazed		Grazed	Ungrazed
Honeoye silt loam...	92	132	30.3	152	153
Ontario loam.......	67	97	30.9	114	134
Volusia silt loam....	66	133	50.3	117	152
Lordstown silt loam.	47	71	33.8	121 .	118

*As measured by actual areas from Figs. 2, 3, 4, and 5.

These differences would have been greater had only the aggregates greater than 2 mm been considered.

The greatest degree of aggregation (considering only the material >1.0 mm in diameter) occurred in the Volusia and Honeoye soils, and the greatest relative decrease of the grazed as compared with the ungrazed occurred in the Volusia and Lordstown soils.

In order to find out if the pore size distribution of the soils differed under grazed and ungrazed conditions, duplicate samples of Volusia soil near Ithaca (experimental area No. XI) were obtained without appreciably disturbing the natural soil structure. The soil pores were filled with water and then increasing increments of tension were applied and the volume of water withdrawn by each successive tension was measured. The process was carried out using the apparatus described by Bradfield and Jamison (2). Equilibrium was not established at any tension, but a given tension was applied until not more than 0.02 cc of water was withdrawn during a 4-minute period. Approximately the same time intervals were used with the grazed and ungrazed samples and the same volume of soil constituted each sample. The results are presented graphically in Fig. 6. It can readily be seen that the only important difference occurred as a result of the application of the first tension. This indicates that any differences in pore-size distribution were concerned with pores larger than 100 microns in diameter.

The data for air temperature, soil temperature, light intensity, and relative humidity of atmospheric air are presented in Table 4. The grazed woodlands, when compared with the ungrazed had higher soil and air temperatures as well as higher light intensities, while the relative humidity of the air was lower.

DISCUSSION

It is not surprising that no consistent difference in pH existed between the grazed and ungrazed soils. The differences that did occur could often be attributed to variations in species composition of the forest stand, correlating fairly well with the theoretical calcium content of the foliage (5).

The higher organic-matter content of the ungrazed soils might be attributed to several causes. Although no actual measurements were

made of the amount of annual leaf-fall on the grazed and ungrazed areas, it seems extremely probable that the amount on the former was considerably less than on the latter. This might have resulted from a lack of a younger understory which hence could not have deposited any leaves. Furthermore, the crown density was reduced considerably due to the low vigor of the trees in the grazed areas, and, therefore, the amount of leaves falling on a given land surface was less. Also, because of greater wind velocity and less shrubby vegetation to hold leaves, there was a tendency for the litter to blow out of the grazed areas, or at least into the depressions. The amount of organic matter added by the dying grass roots was partially offset by the loss in amount of litter.

TABLE 4.—*Air temperature, soil temperature, light intensity, and relative humidity of atmospheric air in grazed and ungrazed farm woodlands.*

Experimental area No.	Air temperature, °C		Soil temperature, °C		Light intensity, percentage of full sunlight		Relative humidity, %	
	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
I	25.0	23.9	24.2	20.0	9.5	1.6	78	81
II	25.6	25.0	21.1	20.0	18.9	2.4	71	75
III	27.2	25.6	23.0	21.0	15.6	9.0	61	71
IV	30.6	27.2	24.1	19.9	30.0	3.6	42	50
V	27.2	25.6	24.5	21.8	9.6	1.5	45	53
VI	29.4	25.6	27.2	21.5	22.0	2.4	41	53
VII	30.6	28.3	25.6	22.3	17.2	3.4	48	62
VIII	28.9	26.7	23.3	19.9	33.0	3.2	51	64
IX	27.8	25.5	22.5	20.3	8.8	1.3	58	75
X	20.0	15.6	23.8	15.1	23.0	1.5	54	77
XI	26.1	25.0	23.1	19.7	34.5	3.5	56	62
XII	27.2	26.7	25.6	21.2	22.8	3.0	53	61
XIII	27.8	26.7	23.1	19.8	14.7	2.5	45	64
XIV	25.0	23.3	21.5	17.5	26.0	4.4	54	74
XV	25.0	23.3	20.1	18.0	11.0	3.5	58	78
XVI	25.6	22.2	22.4	20.2	24.9	2.6	60	73
XVII	29.4	27.2	21.0	22.0	30.1	2.0	41	51
XVIII	29.4	27.2	29.2	21.1	27.1	3.2	49	59
Mean	27.1	25.0	23.6	20.1	21.0	3.03	53.6	65.7
Odds that the difference is not due to chance alone	Infinite		Infinite		Infinite		Infinite	

Morgan and Lunt (15) and Romell (16) have shown that the organic-matter content of the forest soils in the northeastern United States is considerably lower in the warmer, drier sections than in the cooler, more humid ones. Therefore, since slightly higher temperatures as well as somewhat drier conditions obtained in the grazed woodlands, it would logically follow that a lower organic-matter content would exist in the grazed soils under equilibrium conditions.

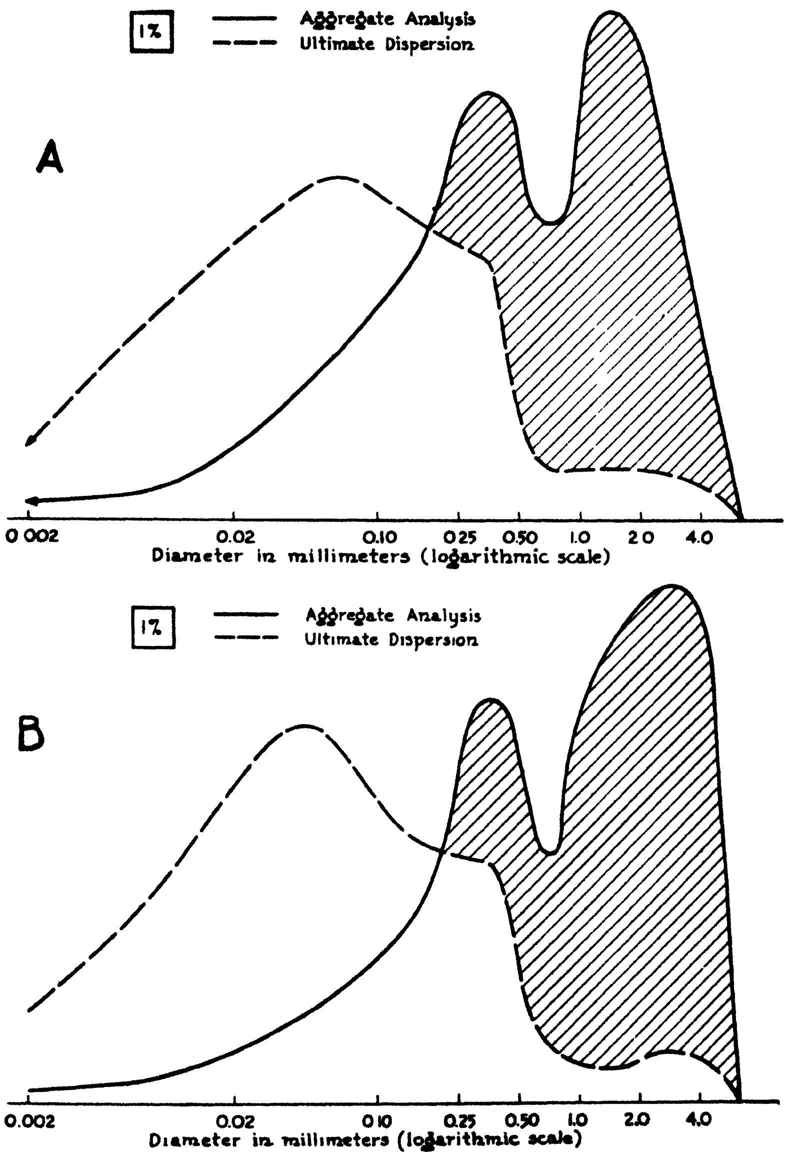


FIG. 3.—Average particle size distribution (area type of curve) for the Ontario loam soils, with and without dispersion. A, grazed; B, ungrazed.

The higher volume weight on the grazed soils might be explained on the basis of several combined influences, *viz.*, (a) the trampling effect of the cattle would tend to compact the soil, (b) the lower organic-matter content might cause an increase in the actual specific

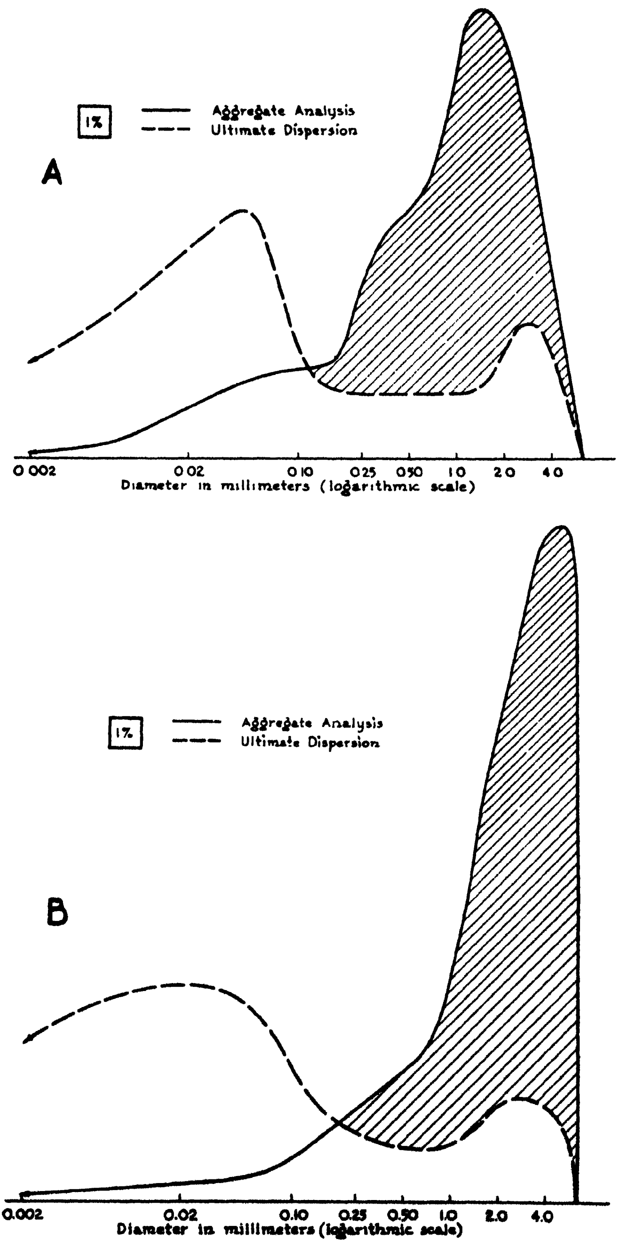
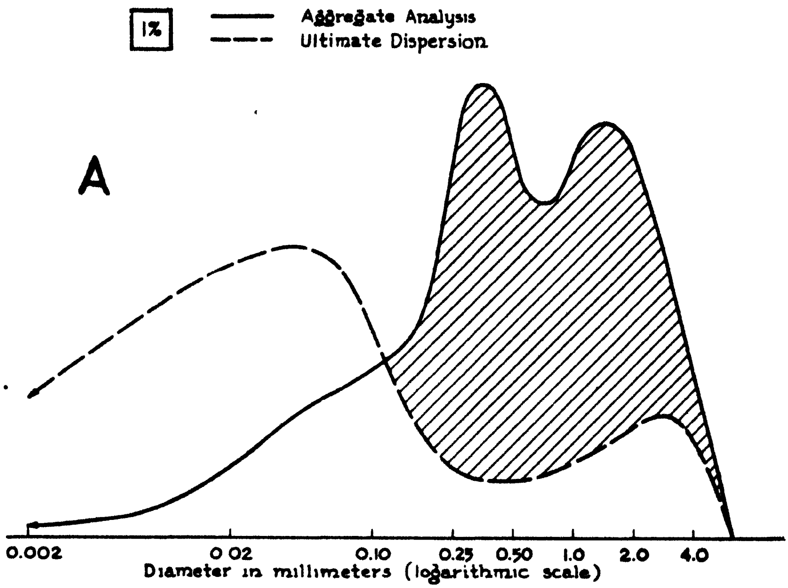


FIG. 4.—Average particle size distribution (area type of curve) for the Volusia silt loam soils, with and without dispersion. A, grazed; B, ungrazed.



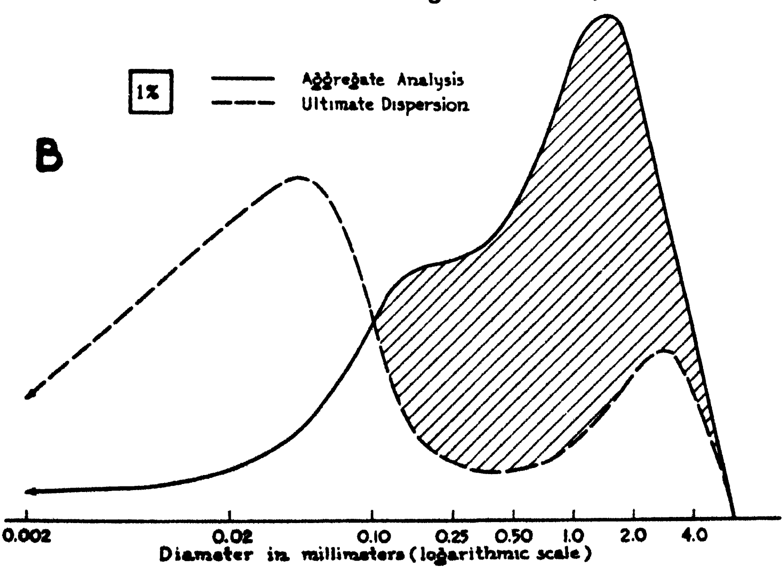


FIG. 5.—Average particle size distribution (area type of curve) for the Lordstown silt loam soils, with and without dispersion. A, grazed; B, ungrazed.

gravity of the soil as a whole and thus increase the volume weight, and (c) the lower percentage of the larger aggregates would be conducive to tighter packing of the soil and hence a reduction in pore space and an increase in volume weight.

Although Zon (21), Craib (7), and other workers have indicated that forest trees remove large amounts of water as compared with other types of vegetation, the fact is brought out by the figures presented in this paper, as well as those by Diller (11), that in spite of a decreased crown area the soil moisture content of the grazed woodlands was consistently lower than that of the ungrazed woodlands. Apparently the increased sunlight and wind velocity produce conditions predisposing toward high rates of both transpiration and soil surface evaporation. That the differences were not brought about by the high organic-matter content of the ungrazed areas is revealed by the fact that the differences were still significant when expressed as relative wetness. These differences are not confined to the surface

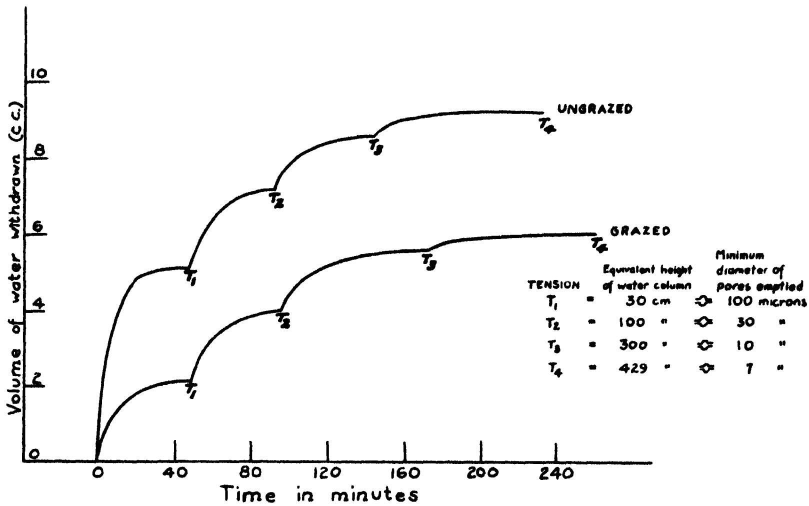


FIG. 6.—Volume of water withdrawn from grazed and ungrazed Volusia silt loam soil by the application of successive increasing tensions.

soil, but, according to Diller (11), extend well into the subsoil. The drier conditions of the grazed soil on sloping areas might be partially attributed to a relative increase in surface runoff on the grazed areas as compared with the ungrazed.

It is possible that the trampling of the cattle had considerable influence in decreasing the proportion of the larger aggregates. Another factor which may have been partially responsible for the differences, but on which no data were obtained, is the abundance and activity of earthworms. In all the ungrazed areas, on which the humus layer type was a coarse mull, signs of intense earthworm activity were noted. Under the grazed woodland areas, observations indicated a lessened intensity of earthworm activity, and in certain cases it was difficult to find any earthworm castings. Those working with forest soil humus layers (17, 13) have generally agreed that the well-developed crumb structure of coarse mull was due primarily to the activity of earthworms. Since the grazed soils are drier and warmer and hence provide a less favorable environment for earthworms, it

would not seem improbable that their decreased activity might be partially responsible for the small number of the larger aggregates. In further support of this, the Lordstown soils, in which no earthworms were found, showed the least total aggregation of all soil types under the ungrazed condition.

The preliminary results obtained in this study would indicate that the soils well supplied with calcium, such as Honeoye and Ontario, held their original surface soil structure under grazing to a greater degree than the more acid Volusia and Lordstown soils. The limited number of observations in this study, however, would not permit any generalizations on this point.

The comparatively large amount of light reaching the ground in the grazed woodlands can be attributed to two principal causes. The understory was missing due to the fact that for 30 years or more no reproduction had been allowed and the crown density was relatively low because of low vigor, as well as the fact that some trees had usually been removed and no young trees were present to occupy the empty spaces. The extra light was undoubtedly the principal cause for the increased soil and air temperatures, and was probably responsible in part for the lower moisture content on the grazed areas.

The high relative humidity under the ungrazed conditions might be ascribed partially to the following factors: The soil was more moist, there were more leaves transpiring water, and the wind movement was considerably decreased.

It is not within the province of this study to determine which of these differences attributed to grazing are the most influential in decreasing the productivity of farm woodlands. Undoubtedly a combination of factors is responsible. We can make the general statement that grazed woodlands as compared to ungrazed ones tend to have a lower organic-matter content, and hence lower water-retaining properties. The volume weight of the soil is generally higher while the proportion of soil aggregates greater than 1 mm in diameter is lower. The actual amount of available soil moisture is usually lower, while the air and soil temperatures are higher and the relative humidity is lower. Considering the fact that forest soils in the humid Northeast are usually moist and cool and the air surrounding the trees is usually rather humid, it is not surprising that the changes associated with grazing reported in this paper cause a less favorable environment for most native forest trees.

SUMMARY

The results of a study of soil and climatic conditions in 18 paired grazed and ungrazed woodland areas can be summarized as follows:

1. No significant differences in pH of the surface soil were found.

2. The soil organic-matter content was higher under the ungrazed conditions, averaging 8.5% as compared with 6.4% for the grazed areas.

3. The volume weight of the grazed soils averaged 1.15, while the ungrazed soils averaged 0.92.

4. The moisture equivalent was higher under the ungrazed conditions and correlated well with soil organic matter content.

5. The moisture content of the soil was highest on the ungrazed areas, whether expressed as percentage of oven-dry soil or as relative wetness.

6. Air and surface soil temperatures were highest in the grazed woodland areas.

7. The amount of light penetrating the forest canopy was much greater in the grazed woodlots, averaging 21% of full sunlight as compared with only 3.03% under the ungrazed conditions.

8. The relative humidity of the air was highest under the ungrazed conditions, being 65.7% as compared with only 53.6% for the grazed woodlands.

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PRELIMINARY RESULTS ON SEED SETTING IN RED CLOVER STRAINS[1]

C. P. Wilsie and N. W. Gilbert[2]

THERE has been considerable interest in the posibility of using some of the European short corolla tube, or so-called "bee clover," strains of red clover in this country. It has been thought that these strains would be more attractive to honey bees because the shorter corolla tubes would facilitate the collection of nectar. A greater attractiveness for honey bees would presumably result in more pollination in the field and, consequently, an increase in seed setting. While generally recognized that it would be unlikely that any of these strains would be highly satisfactory in themselves, it was thought that they might be of value in a breeding program aimed at more dependable seed production.

Preliminary studies on seed setting with three American and three European strains have been conducted during the past two seasons. The American strains included a well-adapted strain from Ohio, the Emerson Iowa strain, and the variety known as Kentucky 101. The European clovers included the Wilson white-blossomed type, the Swiss No. 944, and the Zofka short corolla tube strains. Corolla tube lengths in the different strains as determined in both the first and second crops during the 1939 season are given in Table 1.

TABLE 1.—*Corolla tube length and variability in six red clover strains, 1939.*

Variety	Number of florets	Average length in mm	Standard error	Coefficient of variation, %
Kentucky 101	490	9.09	±0.115	5.50
Wilson (white)	150	8.44	±0.347	10.07
Emerson (Iowa)	490	8.42	±0.135	8.19
Ohio	490	8.35	±0.141	7.38
Swiss 944	250	7.92	±0.161	6.44
Zofka	490	6.93	±0.199	12.55

These values were obtained by measuring the distance from the base of the corolla to the upper limit of the closed portion of the tube as indicated by a faint mark at the base of each wing process.

Kentucky 101 had the longest corolla tubes and Zofka the shortest, the difference between these two being 2.16 mm which is statistically

[1]Cooperative investigations of the Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Iowa Agricultural Experiment Station Journal Paper No. J-697, Project 658. Received for publication January 6, 1940.

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highly significant. It is apparent from the data that the Wilson (white-blossomed) and Zofka strains were considerably more variable than the others.

In 1938 seed yields were determined in the Zofka, Swiss, and Ohio strains. An equal number of heads was harvested from each plot at different times from July 28 to October 4. Seed yields reported in grams of seed per 100 heads are given in Table 2. Statistical analyses show that the Ohio strain is significantly higher in yield than either the Swiss or Zofka short corolla strains.

TABLE 2.—*Seed yields in red clover strains, 1938.*

Strain (500 heads each)	Grams of seed per 100 heads
Zofka	2.75
Swiss 944	2.94
Ohio	4.63

During the 1939 season a more elaborate study was conducted. Heads were collected during August and September and the number of seeds per head determined. Two colonies of bees had previously been located near the red clover plots so that honey bees would be plentiful for pollination work. Results of this study are given in Table 3.

TABLE 3.—*Seed setting in red clover strains, 1939.*

Harvest date	No. of heads	Average number of seeds per head				
		Ohio	Emerson (Iowa)	Kentucky 101	Wilson (white)	Zofka
Aug. 21..	500	79	—	—	—	20
Aug. 23..	150	—	73	76	70	47
Aug. 25..	300	—	70	59	48	24

The data indicate, as in 1938, a significantly lower seed production in the Zofka short corolla tube variety.

A second and more detailed study was made using a smaller number of heads. The number of florets per head, number of seeds per head, and the percentage of florets setting seed were determined. These data are presented in Table 4, 25 heads of each strain being the number examined in each sample.

The results indicate that not only were fewer seeds produced by the Zofka short corolla strain, but that this strain actually had a significantly lower percentage of seed set.

Observations on bee activity in all of the plots showed that, while the number of bees present varied from day to day, and from hour to hour, there were usually considerably more honey bees than bumble bees visiting the flowers. It was noted further that, in the Zofka plots, honey bees and bumble bees were found in approximately equal numbers, while in plots of the Emerson Iowa strain there were usually twice as many honey bees as there were bumble bees. In 17 different counts throughout the blooming period there were 5 times as many

honey bees and 3 times as many bumble bees on the Emerson plots as were present on the Zofka plots. While there were some more flowers present in the Emerson plots, the difference in numbers of flowers was not proportional to the great difference in bee activity noted. The lower percentage of seed setting in the Zofka strain would seem to be a logical result of less bee activity.

TABLE 4.—*Number of florets per head, seeds per head, and percentage of seed set in red clover.*

Harvest date	Strains of red clover			
	Emerson (Iowa)	Kentucky 101	Wilson (white)	Zofka (short corolla)
	Average Number of Florets Per Head			
Sept. 8	106	90	106	81
Sept. 12 . .	106	101	90	74
Sept. 25	94	88	90	70
Sept. 25 . ..	102	82	92	75
Average..	102.0	90.2	94.5	75.0
	Average Number of Seeds Per Head			
Sept. 8	83	74	84	57
Sept. 12	86	79	68	45
Sept. 25	66	58	59	47
Sept. 25	69	59	58	47
Average...	76.0	67.5	67.5	49.0
	Average Percentage of Florets Setting Seed*			
Sept. 8 ..	78	83	70	70
Sept. 12.	81	78	76	61
Sept. 25 . ..	70	66	66	67
Sept. 25.. ...	70	69	63	62
Average ..	74.8	74.0	68.8	65.0

*In percentage of florets setting seed a difference between variety means of 6.65 is necessary for significance at the 5% level.

It appears then that Zofka red clover offers no advantage from the standpoint of attractiveness to honey bees. On the contrary, there is considerable evidence to indicate that the American strains are more attractive to honey bees than is Zofka. It is known that bees visit red clover to collect pollen as well as nectar. While they may carry both, it is likely that at times they are concerned principally with the collection of pollen. Under such circumstances the length of corolla tubes would be unimportant. Bees would tend to visit those heads where pollen was most abundant whether or not they could actually reach the bottom of the corolla tube to obtain all of the nectar present. While no data were obtained, daily observations made while hand pollinating a large number of heads indicated that the American strains probably furnished a much better source of pollen than did the Zofka.

The data presented in this study indicate both less honey bee activity and less seed production in the Zofka strain than in the American strains. Contrary to popular expectations, the length of corolla tube did not seem to be a factor of importance under the conditions of this experiment. It is suggested that possibly the abundance of pollen, secretion of nectar, or concentration of nectar may have been of more importance in determining the attractiveness of red clover strains to honey bees. The data on seed setting indicate that with the well-adapted American strains there would seem to be excellent potential possibiltiies for high yields of seed when conditions are favorable for abundant bee activity.

NOTES

SUGGESTED DESCRIPTIVE TERM "NATURALIZED" FOR ESTABLISHED EXOTIC ECOTYPES OF HERBAGE PLANTS

THE need of a descriptive term for general definition of exotic pasture and hay plants now well established through natural selection and long-continued self-perpetuation is evident to investigators working with herbage plants. This is particularly true of white clover, Kentucky bluegrass, and certain other legumes and grasses that have made up the herbage flora for many years without being artificially reseeded. Such plants may or may not completely or even partially represent the prototypes for in most cases the prototypes are not definitely known. Depending upon the method of pollination or reproduction; the action of certain limiting factors of the environment occurring at periodic intervals, seasonal or otherwise, and the aggressiveness of the plants, populations may consist of several distinct morphological and physiological forms of the same species representing rather a wide ecotypic range. These plants are not native or wild, these terms being synonymous, nor are they spontaneous even though they may seem to appear spontaneously. They are "naturalized" plants, being the surviving progeny of chance or planned plant introductions many of which occurred during the early settlement of this country.

The term "naturalized" is suggested with reference to such plants. In connection with the use of the term "naturalized" it would be essential that the state of origin be given. For example the state of origin could be used in a modifying phrase as "naturalized" white clover of Louisiana or as an adjective such as Louisiana "naturalized" white clover. Since this term is widely used by systematic botanists with the same meaning, its adoption by agronomists would lead to a more complete unity of usage. Any criticism of the term "naturalized" with suggestions regarding other appropriate terms is solicited. —E. A. HOLLOWELL, *Bureau of Plant Industry, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C.*

FOREST SERVICE RANGE RESEARCH SEMINAR

PRESENT knowledge of "grassland" agriculture in America is both meager and poorly organized. The building of a suitable and adequate body of information for showing what constitutes intelligent forage production and for guiding the husbandry of areas to be utilized by grazing has for some time loomed as a major agronomic and ecologic need. Year by year this need has grown more urgent, and judged by present trends, it is not likely to decrease, but on the contrary will doubtless expand to great proportions.

This demand has not been ignored by technical and professional men. More research has been initiated; cultural programs and demonstrations inaugurated; a general awakening has occurred; and groups and individuals are beginning to appraise the basic philosophy of range land husbandry and the programs designed to meet and solve

the problems in this field in a more objective and critical manner than ever before. In keeping with this on-coming expansion in demand for adequate information regarding range forage and range land use and management, a conference of major interest was held July 10–22, 1939, at the Great Basin branch of the Intermountain Forest and Range Experiment Station, near Ephraim, Utah, by the U. S. Forest Service, to take stock of objectives, plans, procedures, and technics applicable to range research problems.

The problems most carefully analyzed at the conference were those dealing with (1) the development of sound research programs based on regional and local problem analysis; (2) research methodology, including experimental design and statistical analysis; and (3) vegetation problems such as forage growth and production, vegetative changes, trends and conditions, utilization of the forage crop and artificial revegetation. Problems dealing with multiple range land use, handling livestock on the range and animal nutrition were also included, as well as those pertaining to publications, recruiting personnel, cooperation with other research agencies, and the need for, and the means of accomplishing, intelligent range extension education.

As in other fields, many of the plans for the early pioneer range investigations largely dealt with local needs and empirical aspects of the range problems. In the recent past an effort has been made to analyze range problems more thoroughly and so to state objectives and to develop the design of the experiments in order that the findings will have more general application and conclusions be founded more nearly on basic principles. The seminar re-emphasized this need and recommended that in the future such a systematically organized program with its necessary procedure be required for all major range research projects.

Papers and discussions pointed out that all future experiments aiming at important conclusions cannot escape being criticized as to whether they embrace acceptable experimental designs involving either hidden or direct replications, randomization, and check treatments. Some research designs and procedures now in operation might also be greatly improved by being slightly revamped in such a way as to make them conform more closely to acceptable designs. Planning research studies in such a way that they are statistically sound is strongly emphasized, with the caution, however, that statistics be regarded as a tool to assist in planning the design and analyzing the data for significant conclusions rather than as an end in itself. Owing to the necessity in range research of obtaining in many cases approximations rather than precisely determined measurement data, the ecologists and agronomists of the conference felt that over-complicated designs and ultra-refined statistical technique had as yet best be avoided.

An analysis of the difficulties encountered in vegetational studies uncovered the acute need for more refined methodology to be used in obtaining range inventories, forage estimates, and utilization surveys. There is also insufficient information regarding the place of enclosures and permanent plots in the experimental design and regarding what

kind of data to take from them. The various intensive methods of studying vegetation are also not fully adequate in their present state of development. Range researchers must always strive to improve the methods and techniques of obtaining more precise measurements and accurate data without losing sight of the ever-constant need of finding at least partial solutions to the economic and biological problems of the range.

The distressing need for more adequate supplies of range forage makes patent the urgency of obtaining new and significant information on how to increase forage production, in learning the nature and degree of utilization to which forage species might, without injury, be subjected, and in establishing the climatic and soil conditions to which the various forage species are adapted. In the important field of artificial range revegetation whole blocks of new information are required, not only regarding adaptability of species, but also as to when, how, and what to reseed; how best to cover the seed; in many cases how to deal effectively with undesirable or low-value vegetation on the ground; and from a practical point of view, how to devise effective and economical methods of artificial revegetation that will produce new stands of vegetation at costs sufficiently low to make the revegetation process a feasible one Likewise, the whole problem of range rehabilitation by better grazing management still needs thorough and incisive study.

It is definitely recognized that information regarding the nutritive values of the various range forages is a critical need, and one on which the comparative value of different ranges must be based. Little information is now available regarding the chemical composition and nutritive value of range forage species at different stages of maturity; nor is practically anything known of the digestibility of these forages at present. Much basic chemical and physiological research is required before an intelligent program of forage requirements and utilization can be established. For example, our information is scant indeed regarding the manner in which intensity of previous use, effects of weathering on mature forage, and loss of rich top soil influence the nutritive value of the forage.

Two supplemental phases of the conference were week-end trips and illustrated evening lectures. The trips consisted of an excursion to the Desert Experimental Range, where practical grazing experiments are under way; one to the terraced and artificially reseeded watersheds, between Salt Lake City and Ogden that have proved effective in flood control; and others to nearby national forests and national parks of southern Utah and Arizona embracing varied range conditions.

Four evening lectures also fortified the technical program and discussions: (1) The 1938 European Grassland Conference, W. R. Chapline, chief of Forest Service range research; (2) The role of geology in interpreting watershed problems, R. W. Bailey, director, Intermountain Station; (3) The ecological plant changes in southwestern Utah, Dr. W. P. Cottam, botanist, University of Utah; and (4) The historical and economic development of Utah since settlement, Dr. W. L. Wanlass, Utah State Agricultural College.

Attendance at the conference included the directors, range research leaders, and most of the men engaged in range research from the six western Forest Service forest and range experiment stations; the assistant regional foresters in charge of range management administration in western national forest regions; Regional Forester C. N. Woods of the Intermountain Region; Director E. L. Demmon of Southern Forest Experiment Station; and Washington officials in charge of range research, range management, and wildlife management.—GEORGE STEWART, *Intermountain Forest and Range Experiment Station, Ogden, Utah.*

BOOK REVIEWS

PLANT PHYSIOLOGY

By E. C. Miller. New York: McGraw-Hill Book Co., Inc. Ed. 2, XXXI+1201 pages, illus. 1938. $7.50.

THE second edition of this excellent book on plant physiology continues the effort so successfully made in the first edition to present an advanced text book in plant physiology and to include contributions from American and English plant physiologists along along with those from Continental workers. The subject matter still deals solely with the green plant, omitting fungi.

The new edition is really more than a text book for advanced students it becomes a handbook of plant physiology and serves as a reference source for an amazing range of topics. Some conception of the addition of material in the 7½ years intervening between the appearance of the two editions may be gathered from the fact that there are 301 additional pages— an increase of one-third. There are over 3,600 individual authors cited in the author index and the subject index lists over 4,500 individual items. These two features of the book alone make it an invaluable addition to any library, office, or laboratory where matters of plant physiology are of interest.

The new material that has been added quite naturally reflects the more recent contributions in plant physiology. They include, for example, a more complete discussion of the general physical and chemical properties of the cell wall; absorption of elements, now including copper, zinc, iodine, and selenium; nitrogen metabolism; translocation of organic compounds; enzymes; growth-promoting and growth-inhibiting substances; and vernalization. (H. B. T.)

FIELD PLOT TECHNIQUE

By Warren H. Leonard and Andrew G. Clark. Minneapolis, Minn.: Burgess Pub. Co. II+271 pages, mimeoprint, fabricoid covers. 1939. $3.25.

OF the many publications on statistical procedure published in recent years this joint product of the Department of Agronomy and Mathematics of the Colorado State College should be especially welcome to the student and teacher of field plot technic. The material which was developed as a lecture course for seniors and graduate students is especially rich in fundamental background and specific examples of various procedures, as well as extensive references in each chapter, questions for discussion, and problems for solution.

It covers the subjects of frequency distributions and methods of testing significance, correlation, analysis of variance and coveriance, and regression. Part 3 takes up plot technic itself and covers such subjects as soil heterogeneity, plot characteristics, design of experiments as applied to various types of agronomic research, theory of sampling, complex experiments and confounding. It ends with a discussion of mechanical procedure for field experimentation.

A 16-page appendix of useful tables concludes the presentation followed by a subject index. The multigraphing seems excellent, giving a clear, and easily readable text, well arranged and clearly presented. (R. C. C.)

AGRONOMIC AFFAIRS

STATE REPRESENTATIVES

PRESIDENT F. J. Alway of the American Society of Agronomy and President W. H. Pierre of the Soil Science Society of America, acting jointly, have designated the following persons to serve as representatives of the two societies in their respective states for the purpose of procuring new members. The representatives for the American Society of Agronomy have also been asked to serve as "correspondents" for this JOURNAL, supplying items of general agronomic interest on changes in personnel, new lines of work undertaken in their section, and all other items that might be of interest to readers of the JOURNAL. The appointments are as follows:

State	American Society of Agronomy	Soil Science Society of America
Alabama	J. W. Tidmore	J. W. Tidmore
Arizona	Ian A. Briggs	W. T. McGeorge
Arkansas	C. F. Simmons	C. F. Simmons
California	B. A. Madson	W. P. Kelley
Colorado	W. H. Leonard	H. W. Reuszer
Connecticut	M. F. Morgan	M. F. Morgan
Delaware	G. L. Schuster	H. C. Harris
District of Columbia	Chas. E. Kellogg	Chas. E. Kellogg
	M. A. McCall (Crops)	
	E. A. Norton (S.C.S.)	E. A. Norton
Florida	F. B. Smith	F. B. Smith
Georgia	W. O. Collins	W. O. Collins
Idaho	K. H. Klages	K. H. Klages
Illinois	W. L. Burlison	R. H. Bray
Iowa	B. J. Firkins	B. J. Firkins
Indiana	J. H. Lefforge	G. D. Scarseth
Kansas	H. E. Myers	H. E. Myers
Kentucky	P. E. Karraker	P. E. Karraker
Louisiana	M. B. Sturgis	M. B. Sturgis
Maine	J. A. Chucka	J. A. Chucka
Maryland	R. P. Thomas	R. P. Thomas
Massachusetts	W. S. Eisenmenger	W. S. Eisenmenger
Michigan	C. E. Millar	L. M. Turk
Minnesota	H. K. Wilson	F. J. Alway
Mississippi	Clarence Dorman	Clarence Dorman
Missouri	W. A. Albrecht	W. A. Albrecht
Montana	M. P. Hansmeier	M. P. Hansmeier

State	American Society of Agronomy	Soil Science Society of America
Nebraska	F. D. Keim	M. D. Weldon
Nevada	V. E. Spencer	V. E. Spencer
New Hampshire	F. S. Prince	F. S. Prince
New Jersey	H. B. Sprague	R. L. Starkey
New Mexico	J. C. Overpeck	J. C. Overpeck
New York	Richard Bradfield	Richard Bradfield
North Carolina	J. F. Lutz	J. F. Lutz
North Dakota	H. L. Walster	H. L. Walster
Ohio	R. M. Salter and L. D. Baver	R. M. Salter and L. D. Baver
Oklahoma	H. J. Harper	H. J. Harper
Oregon	W. L. Powers	W. L. Powers
Pennsylvania	C. F. Noll	C. F. Noll
Rhode Island	T. E. Odland	T. E. Odland
South Carolina	H. P. Cooper	H. P. Cooper
South Dakota	A. N. Hume	A. N. Hume
Tennessee	O. W. Dynes	Eric Winters
Texas	Ide P. Trotter	Ide P. Trotter
Utah	R. H. Walker	R. H. Walker
Vermont	A. R. Midgeley	A. R. Midgeley
Virginia	S. S. Obenshain	S. S. Obenshain
Washington	E. G. Schaffer	S. C. Vandecaveye
West Virginia	Edward H. Tyner	Edward H. Tyner
Wisconsin	Emil Truog	Emil Truog
Wyoming	T. J. Dunnewald	T. J. Dunnewald

A SCARCITY OF MANUSCRIPTS

FOR the first time in many years the JOURNAL is experiencing a shortage of suitable papers for publication. Improvement in the financial status of the Society during the past two or three years has made possible somewhat more expeditious handling of manuscripts, with the result that papers are moving along toward publication at a more rapid rate.

With the new Editorial Board now functioning smoothly, papers are being reported upon promptly and it would be highly desirable if the editors could see more manuscripts. All members of the American Society of Agronomy and of the Soil Science Society of America are eligible to use the pages of the JOURNAL for publication.

"AMERICAN FERTILIZER PRACTICES"

THE NATIONAL FERTILIZER ASSOCIATION has published under the above title a report of a survey among 32,000 farmers in 35 states on the use of commercial plant food. The survey was conducted by representatives of 65 member companies during the fall and winter of 1938–39.

The report is printed, is paper covered, is illustrated with numerous charts, many of which may be redrawn to show state instead of national figures, and is well indexed. A limited number of copies are available at $1.00 each, with special prices for agricultural workers. Communications should be addressed to the National Fertilizer Association, Investment Building, Washington, D. C.

The purpose of the publication is "to present facts informative both to the fertilizer industry and to the great body of agricultural workers of the country, including the staffs of agricultural colleges and experiment stations, extension services, the U. S. Dept. of Agriculture, country agricultural agents, vocational agriculture teachers, editors of farm journals, and others."

BIBLIOGRAPHIES OF THE LITERATURE ON THE MINOR ELEMENTS

THE third edition of the "Bibliography of References to the Literature on the Minor Elements", published February 1, 1939, by the Chilean Nitrate Educational Bureau, contained 4,628 abstracts and references, in a volume of 488 pages.

Owing to its size, it is not practical to continue publication of complete editions of the Bibliography, especially since the volume of material becoming available makes it desirable to publish more frequently. Accordingly, Supplement No. 1, to be published shortly, will contain about 700 abstracts and references, noted since publication of the third edition.

It is planned hereafter to publish supplements at intervals of approximately one year.

A Botanical Index is now available for the third edition and is also being included in the supplements.

NEWS ITEMS

DR. JOHN B. PETERSON, Assistant Professor of Soils at Iowa State College, has been granted leave of absence and is studying as a National Research Fellow in Geology and Geography under the guidance of Dr. W. P. Kelley at the University of California.

DR. FIRMAN E. BEAR was named head of the Department of Soils at the New Jersey Agricultural College and Experiment Station and Professor of Agricultural Chemistry at Rutgers University, effective January first. Doctor Bear has also been named Editor of SOIL SCIENCE.

THE ANNUAL meeting of the Canadian Seed Growers' Association will be held at the University of Manitoba, Winnipeg, Man., June 17 to 19. Mr. W. T. G. Wiener of Ottawa is Secretary-Treasurer of the Association.

DR. GILBEART H. COLLINGS, Professor of Soils at the Clemson Agricultural College, has been recently appointed consulting editor for a new series of agricultural textbooks which will be published by the Blakiston Company of Philadelphia, Pa.

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A COMPARISON OF YIELDS AND COMPOSITION OF SOME ILLINOIS PASTURE PLANTS[1]

R. F. FUELLEMAN AND W. L. BURLISON[2]

AN approach to a solution of some of the problems of pasture yield and management are chemical analyses of forages. Chemical analyses serve the dual purpose of illustrating the nutritive value of pasture crops and species and their actual acre yields of minerals, proteins, and carbohydrates. The protein and minerals contained in forage materials are probably a more rational basis for acre-yield estimations than are dry matter determinations. A number of pasture species have been used for experimental farm pastures at Urbana, Illinois. The Agronomy and Animal Husbandry Departments of the University of Illinois have cooperated in obtaining data from 5- and 10-acre fields of grasses and legumes used for pasturing beef cattle and sheep. In this paper the yields and chemical composition of Reed canary grass (*Phalaris arundinaceae*), Kentucky bluegrass (*Poa pratensis*), orchard grass (*Dactylis glomerata*), and smooth brome grass (*Bromus inermis*) are presented and some comparisons made.

Trends in consumption of brome grass, Reed canary grass, Kentucky bluegrass and orchard grass seem to indicate that, while all are eaten readily by most types of livestock, brome grass is apparently somewhat more palatable. This statement should not be made without qualifications. There are times during the grazing season when animals indicate little preference among species, but not for sustained periods. When consumption records covering a number of years were examined, it was found that there was a marked and sustained seasonal increase in consumption of brome grass over that of other grasses. A higher ratio of consumption to production occurred with brome grass than the other species. Undoubtedly the stage and rapidity of growth, chemical composition, seasonal effects, and many other factors are responsible for apparent differences in palatability. The term palatability expresses the relative taste of materials as indicated by animal preference, although that which may be palatable to one animal may not be acceptable to another of the same type.

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication December 26, 1939.

[2]First Assistant in Agronomy and Head of Agronomy Department, respectively.

Chemical analyses of forages are an aid in the interpretation of pasture experimental results as well as an indication of apparent palatability. They serve as a basis for comparison of the nutritive value of forages and the yield of digestible nutrients. The quantity of protein does not necessarily indicate its quality or digestibility; however, it is true that most high protein forages are apparently more palatable and nutritious than those containing less protein. Similarly, the percentages of phosphorus and calcium are indicators of nutritive value, but this does not mean that they are entirely available to the animal. The percentages of protein, or of minerals, in a sample of forage cut on any given date may vary considerably in comparable samples of the same species. This does not imply errors in analysis, in sampling, or differences due to soil heterogeneity. It is reasonable to assume that the forage itself may be undergoing changes brought about by the synthesis of de-synthesis of materials.

This paper presents briefly some of the results obtained from experimental pastures located at Urbana, Illinois, for the years 1935 to 1937, inclusive.

METHODS

A description of pasture sampling methods used at the Illinois Experiment Station has been published,[3] but it is included in this paper for the convenience of the reader.

Metal cages were used to protect the sample areas from grazing. The cages were constructed from ⅜-inch iron rods welded together to form a frame 4 by 4 feet square by 18 inches high. The corner rods extended 12 inches beyond the bottom of the cage and provided anchorage. The top and sides were covered with heavy 2 by 6 inch mesh woven wire welded to the frame.

A definite procedure was followed in placing the cages. The pastures were divided by imaginary lines into three parts and one set of two cages placed in each part. Three samples were taken from each section of the field on each sampling date. They were designated as "A", "B", and "C", the different sections of the field designated as 1, 2, and 3, so that samples from the first section would be designated as "1A", "1B", and "1C". The "A" samples consisted of herbage plucked or clipped from beneath a cage which had been placed over a representative grazed area at a previous sampling date or when the cattle were turned in. The sample harvested from a representative grazed area was designated as "C", or residual growth, while sample "B" was composed of the herbage which was harvested from beneath the cage placed on the "C" area on the previous sampling date. "B" is the total growth since the previous sampling date. The use of "A", "B", and "C" samples allows for two methods of computing yields and consumption, which for convenience have been termed the "A-C", or "A" method, and the "B" method. Obviously, in using these two methods in making computations, a difference in yield and also in consumption occurs. This is not an error due to sampling, but merely an arithmetical difference. This difference varies with the species of plants present in a pasture. For example, in a pasture containing a high percentage of legumes, the "B" method will usually indicate a much larger yield than the "A" method. Differences occurring between the two methods on gramineous pastures are small, with some exceptions, and the yields more nearly

[3]Fuelleman, R. F., and Burlison, W. L. Pasture yields and consumption under grazing conditions. Jour. Amer. Soc. Agron., 31:399–412. 1939.

approximate each other. Apparently the difference is due to the morphological responses of plants after cutting. Grasses tend to send out new growth from rhizomes and the tiller buds near the soil surface. A legume such as alfalfa sends up new aerial shoots which, when protected from grazing, will greatly increase the yield.

The authors do not presume to select the method which is the more accurate representation of the actual yield from a given pasture. The experience of several seasons sampling seems to indicate that the method used is dependent on the type of forage and the season. Unless a large number of samples are obtained on each sampling date a number of negative yield figures may occur, especially in a system of random sampling. Using the "B" method eliminates the presence of negative yield figures regardless of the condition of the turf or the number of samples or the use of random samples. Results from the use of both the "A" and "B" methods are included so that the reader may judge for himself the more preferable system.

Chemical analyses were made on the "A", "B", and "C" samples. The methods of obtaining samples for analysis have already been described by the authors.[4] Analyses for protein, calcium, and phosphorus are shown in Tables 2, 3, 5, 6, 7, 9, 10, 11, 13, 14, and 15. A few analyses were made for crude fiber, nitrogen-free extract, and fat, but the data are not sufficiently complete for comparisons.

Pastures from which the data were obtained are in all cases practically pure stands of grass. Periodical examination of the forage by hand separations, or other commonly used methods, showed that the brome grass was approximately 87% pure, the Reed canary grass 98%; the Kentucky bluegrass 90 to 98%, and the orchard grass 98%. The influence of other species on the chemical composition is negligible.

DISCUSSION OF RESULTS

A portion of the yield data have been published, but they were expressed as the average of the "A" and "B" methods of sampling. In this paper the resulting "A" and "B" yields are not averaged, but each is given as separate figures.

REED CANARY GRASS

Yields of Reed canary grass for 1935 were not obtained as this field was not used as an experimental pasture. Table 1 shows "A" and "B" total yields for 1936 and 1937, and period yields during these years. Yields of dry matter in 1936 exceeded those of 1937 due to mechanical disturbance of the field in 1937. The season of 1936 was marked by excessive heat and periods of drouth, neither of which apparently was a serious factor in the final results. Yields as calculated by the "A" and "B" methods, respectively, in 1936 were 6,426 and 4,382 pounds of dry matter, a difference of approximately 2,000 pounds. The explanation for this difference is in the very slow recovery of growth of the "B" area during the second sampling period. Recovery was retarded in this period, May 25 to June 25, by dry, hot weather. The "A" growth did not suffer materially. Although there was a moisture deficiency, there were sufficient actively photosynthesizing leaves and stems to make the canary grass productive. During the cool months of late fall this tendency is reversed as

[4] *Loc. cit.*

TABLE 1.—*Reed canary grass yields of oven-dry matter per acre for 1936 and 1937 by "A" and "B" methods of calculation.*

1936			1937		
Cutting date	Period yields dry matter, lbs. per acre		Cutting date	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"
May 26	2,323	2,323	May 4	1,000	1,000
June 26	2,422	307	June 17	3,263	1,523
July 21	260	129	June 23	1,023	0
Aug. 24	958	760	July 16	1,515	806
Sept. 15	463	863	Aug. 13	− 986	94
			Sept. 13	939	139
			Oct. 30	−1,779	233
Total seasonal yield	6,426	4,382		4,975	3,795

between "A" and "B" yields. The "B" yields often exceed "A" yields for the same periods. Obviously the light, moisture, and temperature relationships are apparently less seriously affected in "B" areas than in "A" areas. The latter usually have a matting of dry vegetational material during this period, particularly Reed canary grass. "B" areas are usually free of accumulations of these materials. In 1937 the discrepancy between the "A" and "B" yields of dry matter was less pronounced.

Chemical analyses for protein, calcium, and phosphorus of "A", "B", and "C" samples for 1936 and 1937 are shown in Tables 2 and 3, respectively. All calculations were made on a water-free basis.

TABLE 2.—*Reed canary grass the 1936 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
June 26	8.47	12.63	5.77	0.252	0.367	0.189	0.251	0.359	0.182
July 21	6.61	19.07	4.93	0.298	0.375	0.183	0.225	0.477	0.249
Aug. 24	7.21	14.70	7.01	0.248	0.304	0.223	0.310	0.533	0.341
Sept. 15	13.51	12.60	9.46	0.321	0.270	0.239	0.410	0.400	0.332

Protein content of the "A", "B", and "C" samples of forage usually is highest during the early part of the season and declines steadily as the season progresses. The "B" samples invariably are high in protein because it is young green forage. "A" samples are intermediate between the "B" and "C" forages in protein content. "A" samples combine new growth plus residual material and obviously will be lower in protein. "C" samples, or residual growth are usually lowest, and Reed canary grass analyses for 1936 followed this general trend. A similar trend is found in the calcium and phosphorus content of the

TABLE 3.—*Reed canary grass the 1937 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 6	——	22.69	——	——	——	——	——	0.435	——
June 17	9.07	17.83	6.13	0.244	0.258	0.149	0.269	0.366	0.255
July 16	——	12.91	6.06	——	0.265	0.164	——	0.365	0.255
Aug. 13	7.44	15.88	5.24	0.222	0.314	0.176	0.273	0.376	0.289
Sept. 13	7.13	15.01	5.37	0.223	0.304	0.199	0.307	0.361	0.260
Oct. 30	6.12	14.81	3.93	0.181	0.370	0.108	0.231	0.309	0.175

"A", "B", and "C" forages. Variation between "A" and "C" samples is less marked. It is interesting to note the tendency for the protein, calcium, and phosphorus content in the "A" and "C" forages to increase as the season advances. This is again an illustration of the close relationship of climatic factors, plant growth, and composition. In 1937 all three types of samples show a downward trend in protein content as the season advances. There is a similar trend in dry matter yields.

There was no correlation between precipitation and protein content using "A", "B", and "C" samples. However, there was a significant correlation between dry matter yields of the "B" samples and precipitation. No correlation was found between precipitation and dry matter yields of "A" samples.

BROME GRASS

Brome grass (*Bromus inermis*) has yielded more dry matter of uniformly high nutritive value than other grass crops used in these comparisons. Table 4 shows the seasonal and the period yields of brome

TABLE 4.—*Brome grass yields of oven-dry matter per acre for 1935, 1936, and 1937 by "A" and "B" methods of calculation.*

1935			1936			1937		
Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"		"A"	"B"
May 3	2,341	2,341	May 1	1,252	1,252	May 4	1,194	1,194
May 24	2,473	1,423	May 26	1,579	1,579	June 8	3,548	2,687
June 21	4,099	1,700	June 26	1,834	257	July 1	1,132	693
July 19	1,330	1,839	July 21	– 936	0	July 29	2,012	1,524
Aug. 30	649	2,006	Aug. 25	613	1,076	Aug. 16	– 121	490
Sept. 27	– 252	850	Sept. 15	289	625	Oct. 30	– 486	752
						Nov. 17	– 514	126
Total seasonal yield	10,640	10,159		4,631	4,789		6,765	7,466

grass for the years 1935, 1936, and 1937. Total yields of brome grass more nearly reflected the effect of season than did those of Reed canary grass. Total seasonal yield in 1935 by the "A" method was 10,640 pounds of dry matter and the "B" method 10,159 pounds. This is a comparatively close agreement. In 1936 the yields were 4,631 and 4,789 pounds of dry matter, respectively, for the "A" and "B" methods, again a very close agreement, and in 1937 the yields of dry matter were 6,765 and 7,466 pounds, respectively, for the "A" and "B" methods. Referring to the period yields for each year it will be seen that the "A" yields are usually much higher during the forepart of the growing season when photosynthetic activity is greatest and when the system of cutting which disturbs this process the least is the most conducive to rapid growth. Variations are smaller and yields from the later part of the season more nearly reflect the conditions found on a well-grazed pasture.

Results of chemical analyses of smooth brome grass are shown in Tables 5, 6, and 7. As in Reed canary grass, the seasonal trends in 1935 (Table 5) were marked by some variation; however, there was

TABLE 5.—*Brome grass the 1935 protein, calcium, and phosphorus content of the "A", "B", and "C" forage samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 24 ...	13.58	18.22	15.81	0.392	0.481	0.455	0.272	0.366	0.316
June 21.	10.28	15.18	9.41	0.339	0.437	0.312	0.212	0.345	0.205
July 19 ...	12.31	16.06	10.46	0.370	0.459	0.375	0.227	0.302	0.209
Aug. 30	13.07	18.44	10.02	0.476	0.570	0.436	0.241	0.319	0.194
Sept. 23....	15.59	16.49	11.09	0.553	0.560	0.424	0.202	0.126	0.143

a tendency for the percentage protein content of the "A", "B", and "C" samples each to form a hyperbolic curve. The protein content of the "A" and "C" samples was approximately the same, but that of the "B" samples was considerably higher. Differences in percentages of calcium and phosphorus followed a trend similar to that of the protein. In 1936 the very marked effect of seasonal distribution of rainfall is seen (Table 6) on protein content during the later part of the season. A sharp increase in protein and minerals is noted in "A",

TABLE 6.—*Brome grass the 1936 percentage content of protein, calcium, and phosphorus of the "A", "B", and "C" forage samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
June 26	8.95	15.10	8.37	0.357	0.497	0.357	0.158	0.245	0.170
July 21......	7.16	——	5.86	0.396	——	0.366	0.122	——	0.106
Aug. 24	10.12	20.85	9.99	0.375	0.508	0.329	0.178	0.305	0.145
Sept. 15.....	19.26	25.68	20.26	0.463	0.520	0.428	0.269	0.337	0.249

"B", and "C" samples. The 1937 analyses are comparable to the results obtained in 1935. With a single exception the protein, calcium, and phosphorus contents were uniformly distributed throughout the season (Table 7). The "B" samples were again uniformly high in protein.

TABLE 7.—*Brome grass the 1937 protein, calcium, and phosphorus content of the "A", "B", and "C" forage samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 4	——	22.88	——	——	——	——	——	0.385	——
June 8	11.19	12.80	8.63	0.288	0.306	0.233	0.265	0.307	0.259
July 1	7.76	16.81	8.00	0.236	0.338	0.271	0.268	0.388	0.184
July 29	11.69	17.79	8.20	0.351	0.410	0.300	0.193	0.286	0.159
Aug. 16	14.19	22.62	8.44	0.326	0.427	0.353	0.211	0.322	0.168
Oct. 30	15.06	19.63	13.84	0.439	0.549	0.485	0.200	0.291	0.196
Nov 17	11.48	13.76	8.62	0.466	0.422	0.387	0 170	0.208	0.146

KENTUCKY BLUEGRASS

Yields of bluegrass at Urbana, Ill., have, with the exception of 1935, been invariably smaller than those obtained from brome grass, Reed canary grass, or orchard grass. Periods of high dry-matter production by Kentucky bluegrass usually occur early in the season with a second high in the months of September and October. Precipitation and temperature are apparently closely related to these high production peaks. Mid-summer productivity has usually been low. Maturity usually occurs during May and early June, but during favorable growing seasons, such as 1935, maturity is delayed as contrasted with the season of 1936. In 1935 the grass attained greater heights before heading and leaf growth was more abundant. This is indicated in Table 8 which shows that early period productivity was greater in 1936 than in 1935. Early heading with the attendant stemminess gave larger initial sampling period weights.

Total seasonal production by the "A" method in 1935 was 6,001 pounds of dry matter; by the "B" method 5,304 pounds, a difference of 697 pounds. In 1936, a total of 3,159 pounds of dry matter was harvested by the "A" method and 4,257 pounds by the "B" method, a difference of 1,098 pounds, reversing the increase in 1935 by the "A" method. In 1937, 4,815 pounds of dry matter were produced using the "A" method and 4,078 pounds by the "B" method, a difference of 737 pounds.

As stated previously yields of Kentucky bluegrass usually were smaller than those of brome grass and Reed canary grass, but the protein and mineral composition were somewhat higher. From this it would seem that a smaller yield of bluegrass would more than equal a larger yield of brome grass, but the yield of brome grass was sufficiently larger to offset the differences in composition. Another factor militating against bluegrass is its increased toughness as the summer

TABLE 8.—*Kentucky bluegrass yields of oven-dry matter per acre for 1935, 1936, and 1937 by "A" and "B" methods of calculation.*

1935			1936			1937		
Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"		"A"	"B"
Apr. 26	699	699	Apr. 24	1,408	1,408	May 4	794	794
May 24	1,219	1,413	May 22	747	1,661	June 1	1,971	989
June 21	1,665	1,097	June 19	506	465	July 20	1,030	1,279
July 19	874	1,097	July 1	− 149	0	Sept. 4	1,277	632
Aug. 13	524	494	Aug. 29	487	442	Nov. 15	− 257	384
Sept. 11	1,020	504	Sept. 26	160	281			
Total seasonal yield	6,001	5,304		3,159	4,257		4,815	4,078

advances. This may be associated with the presence of seed stems and partial dormancy during some seasons. It is a matter of common observation that neither sheep nor cattle seem to relish the seed stems, and that bluegrass during this stage of its development does not produce a great abundance of leaves, while brome grass grows sufficiently tall and leafy to provide good grazing.

Tables 9, 10, and 11 show the chemical composition of Kentucky bluegrass for 1935, 1936, and 1937. It should be noted that the bluegrass pasture referred to in this paper was high in fertility which accounts largely for the high yields.

TABLE 9.—*Kentucky bluegrass the 1935 protein, calcium and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 24......	17.91	19.67	16.77	0.348	0.458	0.294	0.334	0.397	0.323
June 21......	14.07	16.66	12.60	0.397	0.370	0.295	0.277	0.178	0.267
July 19......	14.23	18.24	13.84	0.260	0.255	0.234	0.234	0.271	0.182
Aug. 13.....	14.04	18.59	13.97	0.316	0.381	0.361	0.136	0.255	0.211
Sept. 10.....	15.63	18.96	13.87	0.343	0.337	0.300	0.218	0.209	0.210

The term "high fertility" may need some clarification. There are seven or more 10-acre bluegrass pastures on the Animal Husbandry Farm, most of them located on highly fertile soil, but one or two are on soil comparatively low in fertility and consequently relatively low in productivity.

The protein, calcium, and phosphorus content of Kentucky bluegrass shows a protein content equal to, or exceeding, that of brome grass. Calcium and phosphorus, although variable, were approxi-

TABLE 10.—*Kentucky bluegrass the 1936 protein, calcium and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 22......	12.45	12.68	13.22	0.302	0.241	0.272	0.289	0.274	0.287
June 19......	8.53	12.73	8.10	0.199	0.291	0.218	0.139	0.221	0.123
Aug. 1.......	7.53	——	6.98	0.222	——	0.242	0.115	——	0.102
Aug. 29......	12.54	17.72	12.85	0.284	0.351	0.273	0.158	0.212	0.153
Sept. 26......	22.06	24.41	18.66	0.391	0.484	0.404	0.277	0.260	0.245

TABLE 11.—*Kentucky bluegrass the 1937 protein, calcium and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 4.......	——	22.56	——	——	——	——	——	0.441	——
June 1......	12.10	13.14	10.65	1.830	0.206	1.975	0.276	0.282	0.251
July 20......	——	9.87	13.12	——	0.366	0.250	——	0.280	0.198
Sept. 5	10.99	11.68	8.68	0.338	0.417	0.255	0.176	0.375	0.158
Nov. 15	17.61	19.71	——*	0.439	0.510	——*	0.265	0.269	——*

*Insufficient growth for a sample.

mately the same. However, on the basis of yields, total protein and mineral content of Kentucky bluegrass is less than that of brome grass. It is also interesting to note the very large and rapid rise in protein content of Kentucky bluegrass in the late part of the growing season.

In 1935 the seasonal changes in protein content on all samples were small and the low point differed from the high point by approximately 3.5%. The calcium and phosphorus content in 1935, 1936, and 1937 followed similar trends.

The effect of season on composition is very apparent and is more clearly defined when a comparison is made between the composition tables of bluegrass for 1935 and 1936. "B" samples for September 1 are lacking for want of enough growth to provide a sample. It is again emphasized that all samples are composites and no attempt was made to select green material for a sample. From a practical point of view the "A" samples would seem to be more nearly equal to the actual forage consumed by the animal. Chemical composition data are not complete for 1937, but have nevertheless been included for comparative purposes in Table 8. This field was grazed very closely so that on November 15, the final sampling date, insufficient material remained for "C" samples. This is a late date for pasturing in central Illinois, but temperature and moisture conditions were good so the livestock were kept on the pasture.

Kentucky bluegrass still remains as one of the most persistent, aggressive, productive, and economical pasture grasses, when its

relatively high nutritive value based on composition is considered, as well as its apparent palatability.

ORCHARD GRASS

The productivity and chemical composition of orchard grass (*Dactylis glomerata*) usually falls between that of Reed canary grass and Kentucky bluegrass, although considerable variation is found depending upon seasonal effects.

Orchard grass produces well, with the peak of its productivity coming early in the season, and it is during this period that it is consumed most readily by livestock. It has been frequently observed on the orchard grass pastures that when it is in the seed stem stage, cattle and sheep consume less, due to its coarse tough character. It has a second peak in productivity and apparently increased palatability in the late fall, evidently the result of improved moisture conditions and decreased temperatures.

Total seasonal yield in 1935 by the "A" method was 5,906 pounds, by the "B" method 5,533 pounds, a difference of 363 pounds of dry matter in favor of the "A" method (Table 12). In 1936 yields of dry forage by the "A" and "B" methods were, respectively, 4,189 and 3,539 pounds, a difference of 650 pounds favoring the "A" method. Residual growth or the "C" forage remaining on the pasture in 1935

TABLE 12.—*Orchard grass yields of oven-dry matter per acre for 1935, 1936, and 1937 by the "A" and "B" methods of calculation.*

1935			1936			1937		
Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"		"A"	"B"
Apr. 26	799	799	May 27	1,752	1,752	May 4	1,236	1,236
May 24	1,711	1,641	June 26	1,006	504	June 7	3,649	1,109
June 12	——	949	July 21	-92	0	July 1	426	427
July 19	1,675	1,117	Aug. 24	728	529	July 29	1,078	773
July 26	1,008	217	Sept. 15	111	235	Aug. 16	103	190
Aug. 17	100	100	Nov. 11	684	519	Sept. 15	733	183
Aug. 23	236	236				Oct. 23	-818	416
Oct. 15	377	475						
Total seasonal yield	5,906	5,533		4,189	3,539		6,407	4,334

was 917 pounds, in 1936 only 60 pounds, an indication of the effect of season on productivity and consumption. In 1937, the "A" yield of dry forage was 6,407 pounds, the "B" yield 4,334 pounds, a difference of 2,073 pounds. This difference appeared on the second sampling date and was the result of overgrazing during the previous very dry, hot season of 1936. The "B" samples, it will be recalled, are those obtained from a previously clipped, protected area and each sample

represents the growth accruing in the interim. Close clipping necessitates the use of reserves for new top growth.[5] Lacking reserves due to previous depletion would reduce the productivity to a marked degree.

Chemical composition of orchard grass follows the same general pattern of the other grasses. A curve drawn to represent the seasonal trend in composition is usually in the form of a hyperbola and falls between that of brome grass and Reed canary grass, although here again there are seasonal variations. A point of interest is the relatively high and uniform calcium content of orchard grass compared with either brome grass or bluegrass. The phosphorus content is low, although considerable variation occurs with respect to the year. Tables 13, 14, and 15 present the protein, calcium, and phosphorus content of orchard grass.

Composition of orchard grass has varied more from year to year than have the other grasses, particularly in the case of the protein content. The very small protein percentages in the case of "A", "B", and "C" samples for 1937 are interesting, but again are explainable on the basis of depleted food reserves as a result of the excessive hot, dry season of 1936.

TABLE 13.—*Orchard grass the 1935 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 24	12.55	13.19	11.52	0.343	0.319	0.309	0.292	0.338	0.346
June 11*	——	14.84	9.10	——	0.400	0.334	——	0.455	0.282
July 26	11.12	13.49	8.49	0.381	0.438	0.402	0.335	0.421	0.165
Oct. 15	11.93	14.51	10.42	0.449	0.497	0.455	0.196	0.177	0.232

*No "A" sample obtained for chemical analyses.

TABLE 14.—*Orchard grass the 1936 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
June 26	7.94	15.88	6.00	0.376	0.532	0.323	0.192	0.298	0.211
July 21	5.34	——	6.37	0.333	——	0.247	0.176	——	0.146
Aug. 24	11.46	17.78	6.31	0.364	0.493	0.323	0.171	0.261	0.143
Sept. 15	18.89	22.09	22.62	0.540	0.523	0.483	0.298	0.293	0.298
Nov. 11	23.88	29.92	25.22	0.468	0.478	0.510	0.386	0.422	0.391

Some observations on orchard grass indicate that it lacks apparent palatability. On the basis of chemical analyses the answer cannot be

[5] GRABER, L. F. Food reserves in relation to other factors limiting the growth of grasses. Plant Physiology, 6:43–72. 1931.

TABLE 15.—*Orchard grass the 1936 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 5	—	18.19	—	—	—	—	—	0.386	—
June 7.......	6.25	8.63	6.68	0.214	0.181	0.180	0.255	0.405	0.276
July 1......	5.31	14.48	3.75	0.188	0.289	0.177	0.217	0.346	0.235
July 29......	7.38	12.14	6.37	0.242	0.387	0.270	0.221	0.398	0.192
Aug. 16......	8.68	14.19	7.63	0.286	0.370	0.307	0.207	0.318	0.208
Sept. 15.....	8.58	14.29	6.87	0.333	0.421	0.309	0.169	0.269	0.135
Oct. 23...	11.73	16.59	9.25	0.361	0.342	0.321	0.221	—	0.182

found in its protein content alone, although from the 1937 analyses some cognizance must be given this point. It may be partly due to the quality of the proteins or the low phosphorus content. Another factor not presented here, namely, the crude fiber content, indicates that orchard grass and Reed canary grass contain a larger percentage of fiber than do brome grass or Kentucky bluegrass. This perhaps militates against the apparent palatability of orchard grass to livestock; however, orchard grass seldom is used in pure stands as a pasture but is more often included in pasture mixtures used in central and southern Illinois. Animal gains on orchard grass, brome grass, Reed canary grass, and Kentucky bluegrass will be discussed in a subsequent paper and will serve to clarify the picture of palatability based on consumption and animal preference.

No attempt is made to draw conclusions from the data obtained on these pastures at the present time. The experiments are being continued and the results will be presented at a future date. The material presented in this paper indicates certain definite trends and relationships and these trends and relationships become more clearly defined as the volume of data increases.

SUMMARY

Data are presented showing the yields of oven-dry forage from Reed canary grass, brome grass, Kentucky bluegrass, and orchard grass pastures at Urbana, Illinois. Chemical analyses of "A", "B", "C" forage samples are tabulated and indicate the protein, calcium, and phosphorus content of the above grasses. Comparisons of the yield and composition show that brome grass has yielded more oven-dry forage per acre than the other grasses discussed. In terms of total digestible nutrients produced per acre brome grass has also outyielded these other grasses, but on the basis of percentage composition Kentucky bluegrass usually contains more digestible nutrients per pound than brome grass, Reed canary grass, or orchard grass.

Considerable variability in composition was found in the same species in different seasons. This was apparently a seasonal effect due in part to previous management, to type of livestock used, or to the physiological effects of environment, more specifically precipitation

and temperature. The data on the chemical composition of the forage grasses discussed in this paper are in the form of hyperbolic curves, the reverse of the seasonal temperature curves which were in the form of parabolas.

Yields as calculated by the "A" and "B" methods usually vary from each other depending on season and previous treatment of the pasture. Following the season of 1936 forage yields of a bunch-type grass, such as orchard grass, showed larger differences between "A" and "B" yields than did the sod-forming bluegrass and brome grass.

THE CHEMICAL COMPOSITION OF PASTURE SPECIES OF THE NORTHEAST REGION AS INFLUENCED BY FERTILIZERS[1]

B. A. Brown[2]

THE literature on this subject was well reviewed and discussed in several papers presented at a symposium on pastures before a joint session of the Northeastern Section of this Society and Section O of the American Association for the Advancement of Science at Atlantic City, New Jersey, December 29, 1936. Those papers were published in this Journal (Vol. 29:441–511, 1937). Because of that rather recent and exhaustive review, no literature is cited here.

The purpose now is to present in brief form some of the pasturage analyses made since 1931.[3] No attempts will be made to interpret these data in terms of animal nutrition. Such interpretations must await the results of carefully conducted feeding trials, of which there have been very few involving pasturage. In the opinion of the writer, there is a great need for experiments to determine the effects of different kinds of forage on various classes of livestock. However, judging from the growth records of hundreds of dairy heifers which have grazed our experimental pastures for many seasons, animals do not reflect rather wide variations in certain chemical constituents of pasturage, provided there is a sufficient quantity of it. This does not mean that the efficiency values of a given amount of *dry matter* from even slightly different kinds of pasturage may not vary markedly.

PERMANENT PASTURES[4]

Over 300 samples of freshly grown herbage, approximately 4 inches high, were collected during the 5 years, 1932 to 1936. They represent 17 2-acre plots on which production was measured by rotational grazing with dairy heifers. The soil is Charlton fine sandy loam, naturally acid (pH 5.2), and very deficient in easily soluble phosphorus.

The important species in the samples were the four that occur naturally in this region, as follows: (1) Kentucky bluegrass (*Poa pratensis*), which varied from 1% on the unfertilized plot to 50% on the mineral (PL or PLK) pastures and to 75% under mineral plus N treatments; (2) Rhode Island bent grass (*Agrostis tenuis*), a species that maintains a much more uniform stand than bluegrass under the varied conditions; (3) wild oat or "poverty" grass (*Danthonia spicata*), which occurred only on the non-phosphated plots; and (4) white clover (*Trifolium repens*). During the period under consideration,

[1]Contribution from the Department of Agronomy, Storrs (Connecticut) Agricultural Experiment Station, Storrs, Conn. Also presented at the annual meeting of the Society, held in New Orleans, La., November 22, 1939. Received for publication January 13, 1940.

[2]Associate Agronomist.

[3]The analyses were made at the Connecticut Agricultural Experiment Station, New Haven, under the supervision of Dr. E. M. Bailey.

[4]The treatments under test and an explanation of symbols may be found in Table 1.

this legume occupied only from 10 to 15% of the area in the PL or PLK pastures, except the one which received the first P in 1932, where clover reached a peak of 70% in 1933. The no P and mineral plus N plots had small amounts (5% or less) of clover. Because of its low habit of growth, the samples contained less clover than indicated by the percentages of occupied area.

Besides these four, small amounts of sweet vernal grass (*Anthoxanthum odoratum*) occurred in all of the pastures. In general, most of the samples from all plots receiving P consisted of blue and bent grasses; from the non-phosphated plots, of bent and poverty grass. Each sample was analyzed for ash, protein, fiber, N-free extract, ether extract, P, K, and Ca. The season's samples from a few plots were composited and analyzed for Si, Fe, Al, Mn, S, Cl, and Mg.

To save space, only the 5-year averages are given here. However, it may be stated that the variations between annual averages for any given plot were not greater than the intra-seasonal differences, a point to be discussed later. The "feed" and major mineral constituent analyses, shown in Table 1, indicate a generally high feeding value for the pasturage of all plots, except those without fertilizer P. The latter group produced herbage containing only about 75% as much protein and 60% as much P, but considerably more fiber and N-free

TABLE 1.—*Chemical composition of pasturage from grazed plots as affected by fertilization, averages of all analyses for 5 years, 1932–36.*

Fertilization*	Plots in group	Dry matter %	Analyses as percentage of dry matter								Ca:P Ratio
			Ash	Protein	Fiber	N-free extract	Fat	P	K	Ca	
No P†	3E, 5	30.8	8.0	18.1	23.4	46.9	3.62	0.21	2.13	0.61	2.9
P and PK	2E, 2W, 7E	26.3	8.0	22.7	21.7	43.8	3.91	0.32	2.43	0.66	2.0
PL and PLK	1N, 1S, 8N	26.1	8.3	24.3	21.1	42.4	4.05	0.34	2.45	0.69	2.0
PLK‡	3W	25.1	8.3	24.0	21.1	42.7	3.95	0.35	2.31	1.01	2.9
PLK§	8S	26.5	8.4	23.1	21.4	43.2	3.99	0.28	2.49	0.65	2.3
PKN1	9N	24.3	8.1	26.1	21.5	40.2	4.12	0.35	2.71	0.55	1.6
PKN2	9S	24.4	8.2	24.6	21.6	41.5	4.04	0.34	2.41	0.56	1.6
PKN3	7W	24.8	8.3	24.5	21.6	41.8	3.89	0.34	2.59	0.57	1.7
PLKNN1	6N	26.0	8.1	27.5	20.9	39.3	4.24	0.33	2.69	0.57	1.7
PLKN12	6S	25.3	7.9	26.4	21.1	40.4	4.18	0.33	2.59	0.56	1.7
PLKN23	4S	24.7	7.8	26.1	21.4	40.4	4.21	0.36	2.62	0.52	1.4
PLKN123	4N	24.9	7.9	26.9	21.2	39.8	4.26	0.37	2.62	0.52	1.4
All N plots	—	24.9	8.1	26.0	21.3	40.5	4.13	0.35	2.60	0.55	1.6

*P = Superphosphate (16%) to supply a total of 320 pounds of P_2O_5 per acre from 1924 to 1935.
K = Muriate of potash to supply a total of 200 pounds of K_2O per acre from 1924 to 1935.
L = Limestone, a total of 2 tons per acre from 1924 to 1932.
N = Nitrogen at 28 pounds per acre annually.
NN = Nitrogen at 56 pounds per acre annually.
On most of the plots the *total* amounts of superphosphate and potash were divided equally between 1924, 1929, 1932, and 1935 applications; the limestone equally between 1924 and 1926 additions. The nitrogen was supplied by a 2:1 sulfate of ammonia-nitrate of soda mixture through 1934 and by Calnitro thereafter.
The numbers following the letters "N" or "NN" refer to time of applying the nitrogen: 1 means April, 2, June; and 3, August applications.
†The No-P group includes the unfertilized and LK plots.
‡First P applied in 1932.
§No P since 1924.

extract. Superphosphate alone caused the greatest improvement of any single fertilizer. This might be expected because of the extremely P-deficient state of most pasture soils in the Northeast. Adding limestone with the superphosphate further increased the desirable chemical characteristics of the pasturage. The influence of large proportions of clover on the Ca content is evident for plot 3W, where superphosphate was applied for the first time in 1932. Also, the somewhat lower percentage of protein plus the distinctly reduced P content may be noted for 8S, where no superphosphate has been added since the original treatment of 500 pounds per acre in 1924. Nevertheless, in 1938, or 14 years after the *first* and *last* application of P on 8S, the vegetation there contained about 40% more P than that from the unfertilized plot.

The several pastures receiving N, in addition to minerals, produced forage slightly richer in N and P but appreciably lower in Ca. This reduction in Ca is thought to be due partly to less clover and partly to the greater prevalence of bluegrass, which (as will be shown later) contains less Ca than bent grass, the other most dominant species on these pastures.

The Ca:P ratios vary from 1.4 for the high N plots to 2.9 for the no P and the recently phosphated pastures. The relatively high ratio of the no P group is due to the very low amount of P, while in the case of the recently phosphated plot, it traces to the larger amount of Ca in white clover which prevailed there during the period under discussion.

It is interesting to note that the P values fall for the most part between 0.32 and 0.37% or slightly above what has been termed the "critical point" for Kentucky bluegrass. ("Critical point" is the lowest nutritional level at which a species will produce optimum yields.) However, these P values are appreciably below those published for bluegrass grown in Kentucky. That these differences are due to the level of readily available P in the soil is indicated by the annual P analyses of the vegetation from a few plots (Table 2). It is readily apparent that in the years when superphosphate was applied, the P contents of the pasturage rose appreciably, over 20% in one case. There is also a noticeable trend upward with each succeeding P treatment.

TABLE 2.—*Phosphorus in pasturage.*

Fertilization*	P in dry matter, %				
	1932†	1933	1935†	1936	1938†
P	—	0.31	0.37	0.33	0.39
⅓ P annually	—	0.32	0.32	0.32	0.32
PL	0.37	0.33	0.39	0.34	0.39
PLK	0.39	0.34	0.38	0.34	0.43
PLK (P in 1924 only)	0.32	0.28	0.30	0.28	0.28
PLKNN1 and N12	0.35	0.30	0.40	0.32	0.41

*See Table 1 for explanation of symbols.
†Years when superphosphate was applied to all plots unless otherwise noted.

Applying one-third of the superphosphate each year resulted in a very uniform *annual* P content of the herbage. Probably there is no practical advantage in obtaining such *annual* uniformity, for a change in age or in weather conditions has caused greater intra-seasonal differences in the P contents of pasture plants.

The Si, Fe, Al, Cl, S, Mn, and Mg analyses for six differently fertilized pastures are given in Table 3. The outstanding features of

TABLE 3.—*Some other elements in pasturage, averages for 1932–36.*

Fertilization*	Analyses as % of dry matter						
	Si	Fe	Al	Cl	S	Mn	Mg
None	1.64	0.040	0.037	0.75	0.27	0.033	0.19
P	0.84	0.021	0.019	0.68	0.28	0.034	0.22
PK	0.69	0.016	0.012	0.85	0.29	0.033	0.23
PL	0.86	0.023	0.024	0.79	0.30	0.019	0.23
PLK	0.82	0.021	0.024	0.72	0.30	0.021	0.24
PLKNN1	0.59	0.019	0.016	0.87	0.33	0.020	0.22

*See Table 1 for explanation of symbols.

these data are the relatively high amounts of Si, Fe, and Al in the unfertilized vegetation, their values being nearly double those for the other plots. The percentages of S and Mg in the herbage from the untreated pasture are slightly below those from any of the others.

Among the five fertilized plots represented in this study, there appears to be no consistent influences of K, L, or N on the percentages of Si, Fe, Al, Cl, or Mg. S is somewhat higher in the herbage that received N and in turn the PL and PLK pasturage is slightly above that from the P or PK plots.

Mn exhibits the most consistent differences, the values for the three unlimed plots each being about 60% above those for the three limed ones. It has long been known that the availability of Mn to plants is greatly reduced by liming the soil. In this case, the reaction of the upper 3 inches of soil from the limed pastures was pH 5.73 or only 0.46 pH above the unlimed soil. The lower layers of soil from the two groups had even smaller differences in reactions.

INTRA-SEASONAL VARIATIONS

For this study, the samples of 1931 are included with those of 1932 to 1936, making a total of 356. These are divided into six groups according to the season when they were collected. Four of the groups correspond exactly to calendar months, but the first period extends only to May 20, while the second does not end until June 30. These irregular periods were adopted to avoid having any flowering or headed grasses in the first period and to cover in the second the entire time of normal flower and seed development. Even when kept grazed to a very few inches in height, grasses will develop some stems and heads which have considerable influence on the chemical composition.

The averages, given in Table 4, have the following conspicuous features: (1) Total ash is very high in October; (2) protein is highest

TABLE 4.—*Intra-seasonal differences in the chemical composition of pasturage, averages of 1931–36.*

Period when sampled	No. of samples	Dry matter, %	Analyses as % of dry matter								Ca:P ratio
			Ash	Protein	Fiber	N-free extract	Fat	P	K	Ca	
Before May 20......	77	26.2	7.4	26.9	19.4	41.8	4.50	0.35	2.56	0.57	1.6
May 20–June 30 .	88	25.9	7.6	23.2	23.2	42.3	3.70	0.30	2.38	0.64	2.1
July	61	27.8	8.0	22.2	23.1	42.8	3.91	0.29	2.31	0.68	2.3
August....	47	25.7	8.2	24.0	21.8	42.0	3.99	0.32	2.41	0.65	2.0
September.	69	25.8	9 0	24.5	20.7	41.9	3.96	0.33	2.56	0.67	2.0
October...	14	30.4	10.5	20.3	20.4	45.2	3.68	0.31	2.27	0.61	2.0
Total or average .. .	356	27.0	8.4	23.5	21.4	42.7	3.96	0.32	2.42	0.64	2.0

in early May and lowest in October; (3) fiber is lowest in early May and highest in late May and June; (4) fat is much higher in early May than in any of the other periods, June and October having somewhat lower values; (5) the P peak is reached in early May, the low point in July, the low July value probably being due to less moisture in the soil as lack of moisture generally has an unfavorable effect on the amount of that element in pasturage; and (6) Ca is lowest in early May and highest in July or just the reverse of P, a common observation, the causes, however, having not yet been determined.

These intra-seasonal fluctuations have been calculated as percentages of the averages of the respective plots for each season. Frequently such values exceeded 25% and in a few cases reached 40% of the annual means. Ash, protein, and Ca are the constituents which have varied by 40% or more. These facts indicate how difficult it will be to obtain, for any length of time, *fresh* forage of uniform chemical characteristics for experiments to determine the exact feeding values of pasturage.

SEEDED PLOTS

In Table 5 are tabulated the N, P, K, and Ca analyses for timothy seeded with red clover in 1931 and mowed June 1 in each of the 5 years, 1933 to 1937. The entire field had the same mineral (PLK) treatments, but the N varied from 0 to 28 and to 56 pounds per acre. The N was furnished in the form of a 2:1 sulfate of ammonia-nitrate of soda mixture in 1933 and 1934 and as Calnitro in the last 3 years.

Superphosphate (16%) at 500 pounds and muriate of potash (50%) at 200 pounds were added in 1936, the first P or K applied since 1930. These fertilizers had an appreciable effect in raising the P and K in the timothy in 1936 and to some extent in 1937. Although

TABLE 5.—*Timothy, mowed June 1, as affected by fertilization, average of duplicate plots.**

Nitrogen, lbs. per acre annually	Analyses as % of dry matter					
	1933	1934	1935	1936	1937	Average
			Nitrogen			
None	2.09	1.95	1.63	2.12	2.05	1.97
28	2.08	2.03	1.82	1.95	2.04	1.98
56	2.22	2.30	2.08	2.22	2.13	2.19
			Phosphorus			
None	0.28	0.26	0.24	0.31	0.29	0.28
28	0.30	0.24	0.22	0.36	0.28	0.28
56	0.28	0.25	0.22	0.30	0.27	0.26
			Potassium			
None	1.85	1.70	1.53	2.26	2.13	1.89
28	1.86	1.68	1.25	2.31	1.67	1.75
56	1.62	1.35	1.10	2.32	1.27	1.53
			Calcium			
None	0.73	0.69	0.55	0.59	0.59	0.63
28	0.67	0.67	0.66	0.55	0.60	0.63
56	0.64	0.72	0.65	0.57	0.60	0.64

*N applied annually in April and supplied by 2 parts sulfate of ammonia and 1 part nitrate of soda in 1933-34; by Calnitro in 1935-37. P_2O_5 at 80 pounds and K_2O at 100 pounds in 1936.

the timothy was 12 to 15 inches high and much older than the 4-inch bluegrass from the permanent pastures, their P contents in 1936 were practically the same.

Nitrogenous fertilizers have been widely recommended for the purpose of increasing the N or protein content of grass hay. In that respect, even this very early cut timothy was not increased at all by 28 pounds of N and by only about 10% by the 56 pounds of N. Other data from this experiment show that early cutting is much more influential than nitrogenous fertilizers.

Excepting 1936, the K values are much lower for the timothy receiving the heavier amount (56 pounds) of N. This indicates a lack of proper balance in the supply of those nutrients.

In another experiment, Kentucky bluegrass and Rhode Island bent grasses were seeded in pure cultures in August, 1935, on soil with a pH of 5.3 and well supplied with P and K. In 1936 and succeeding years, triplicated 25 by 6 foot plots of each grass were treated with sufficient amounts of several nitrogenous fertilizers to furnish 84 pounds of N per acre, divided into April, June, and August applications. The grasses were cut when 3½ inches to 1 inch with a motor lawnmower, the clippings removed, weighed, and sampled.

In 1938, the third year of the experiment, the samples were analyzed for N, P, K, Ca, and Mg. The effects of the different N carriers on the N, P, and Ca contents of the grasses are shown graphically in Figs. 1, 2, and 3 and on the percentages of K and Mg in Table 6.

TABLE 6.—*Effects of sources of N on the Mg and K contents of grasses.*

Source of N	% in dry matter			
	Kentucky bluegrass		Rhode Island bent grass	
	Mg	K	Mg	K
$NaNO_3$	0.28	1.28	0.28	1.59
$(NH_4)_2SO_4$	0.27	1.12	0.27	1.70
$Ca(NO_3)_2$	0.30	1.21	0.30	1.25
Urea	0.28	1.23	0.30	1.43
Urea + Na_2SO_4	0.26	1.59	0.25	1.80
Calnitro (84 lbs. N)	0.39	0.98	0.31	1.51
Calnitro (168 lbs. N)	0.46	0.81	0.42	1.25

From the graphs, it is readily apparent that on this acid soil the use of the physiologically acid salts, $(NH_4)_2SO_4$ and especially NH_4Cl, resulted in lower N, P, and Ca contents in both grasses. In respect to N, $(NH_4)_2CO_3$ was equally as poor as NH_4Cl but it did not depress the Ca and P. Urea had much more favorable effects than the ammoniates especially in regard to the percentages of Ca and P. Adding NA_2CO_3 at 330 pounds or Na_2SO_4 at 495 pounds per acre, with urea, apparently had little effect on the N contents of either grass, depressed the Ca in both species, and gave contradictory results for P.

Among the physiologically alkaline carriers, cyanamid was somewhat inferior, judging from the N and P contents of the grasses. However, cyanamid and $Ca(NO_3)_2$ were responsible for the highest values for Ca. In this experiment, $NaNO_3$ is the third Na salt to reduce Ca in the grasses, indicating a retarding effect of Na on the availability or absorption of Ca.

Calnitro, a neutral carrier, has high values for N, but is slightly inferior to cyanamid when the analyses for Ca and P are considered. It is very noticeable that this fertilizer, which contains dolomitic limestone, increased the Mg and decreased the K contents of the grasses. (See Table 6.) Na_2SO_4 had just the opposite effects. In the case of bent grass, $(NH_4)_2SO_4$ appears to have increased the K, but this is not true of bluegrass. The K values are quite high for the grass samples from the $NaNO_3$ plots, probably due to replacement of K by Na in the soil exchange complex. This explanation would apply also to the other Na compounds.

In general, these data illustrate what marked changes in the mineral contents of grasses may be caused by using different sources of N or adding other chemicals not commonly used as fertilizers. Although grazing animals may thrive on pasturage of widely varying mineral contents, it seems probable that the chemical composition of a species could be changed to a point where its nutritive value might be either seriously reduced or greatly improved. When one considers that each of the many elements in grasses may occur in greatly different proportions, determining the feeding values of pastures appears to be a very complicated problem.

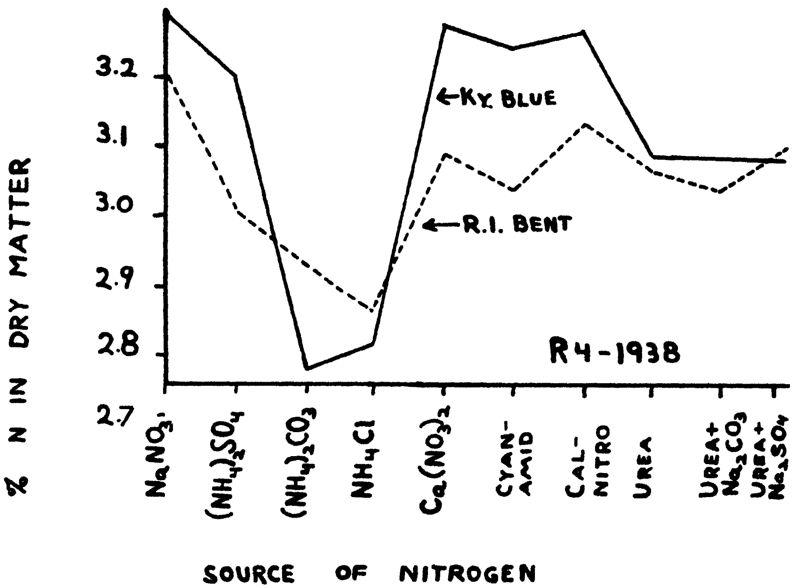

FIG. 1.—Effects of source of N on the N contents of Kentucky bluegrass (*Poa pratensis*) and Rhode Island bent grass (*Agrostis tenuis*).

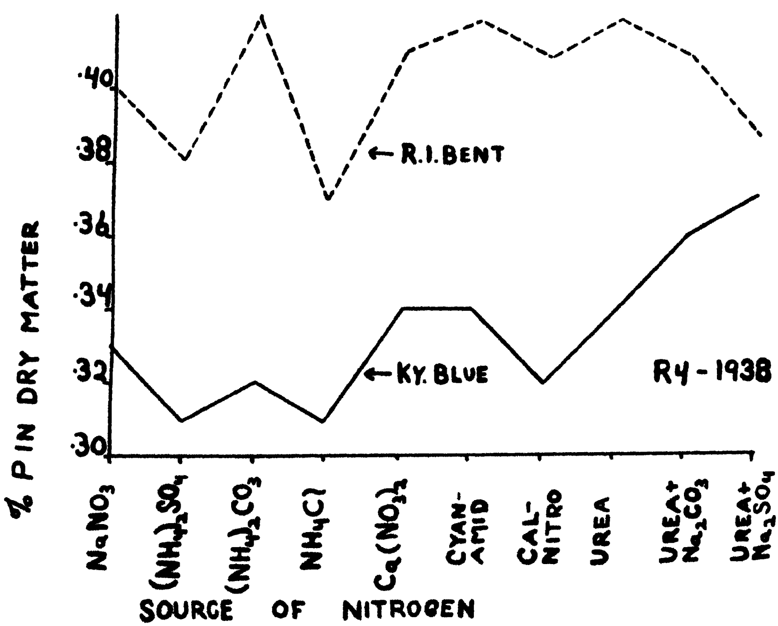

FIG. 2.—Effects of source of N on the P contents of Kentucky bluegrass (*Poa pratensis*) and Rhode Island bent grass (*Agrostis tenuis*).

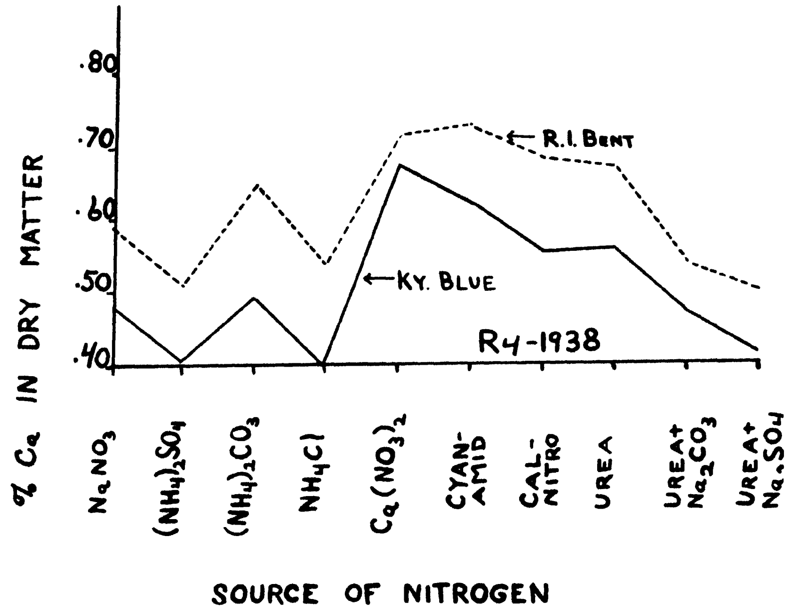

FIG. 3.—Effects of source of N on the Ca contents of Kentucky bluegrass (*Poa pratensis*) and Rhode Island bent grass (*Agrostis tenuis*).

SUMMARY

Chemical analyses of over 300 samples of pasturage from 17 variously fertilized permanent, grazed plots were made from 1932 to 1936. The fertilizers ranged from superphosphate alone to complete minerals (PLK) plus 84 pounds of N per acre annually.

Superphosphate caused the greatest improvement in important nutritional characteristics, namely, a 25% increase in protein, a 5% decrease in fiber, and a 50% increase in P. In these respects, further advances were due to adding limestone and, or, nitrogenous fertilizers with superphosphate.

Superphosphate (16%) at 500 pounds per acre in 1924 was responsible for a 40% increase in the P in the pasturage in 1938. This emphasizes the importance of conducting pasture experiments over long periods.

The Ca:P ratios varied from 1.4 for the PLK plus high N plots to 2.9 for the non-phosphated pastures.

The Si, Fe, and Al contents of the unfertilized vegetation were each approximately double those found in the P or P+ pasturage. Mn was consistently 60% higher in the grasses from the unlimed plots. S, Cl, and Mg did not vary so much as the elements just mentioned and the effects of fertilization were much less evident.

Intra-seasonal variations in composition of samples from the same plot were equivalent to 25% frequently and 40% occasionally, of the annual means. These facts illustrate the difficulty of obtaining *fresh* pasturage of uniform quality for feeding trials.

The N content of timothy, mowed June 1, was not increased by 28 pounds of N but was raised by 56 pounds of N per acre applied annually in April. In this case, early cutting was a much more important factor than nitrogenous fertilizers.

On seeded, lawnmowed plots, the N, P, K, Ca, and Mg contents of pure stands of Kentucky bluegrass and Rhode Island bent grass were influenced appreciably by the source of fertilizer nitrogen. Materials carrying Na increased the K in the grasses, while magnesic fertilizers had the opposite effect. On this soil (pH 5.3), the use of physiologically neutral or alkaline N carriers resulted in higher N, P, and Ca contents in the grasses.

It is concluded that many carefully conducted feeding trials will be required before the results of chemical analyses of pasturage can be interpreted in terms of nutritional values.

EFFECT OF FREQUENCY OF CUTTING ON THE GROWTH, YIELD, AND COMPOSITION OF NAPIER GRASS[1]

C. P. WILSIE, E. K. AKAMINE, AND M. TAKAHASHI[2]

NAPIER grass (*Pennisetum purpureum* Schum.) has found an important place among the forage crops of Hawaii. It is a rank-growing, perennial grass, aggressive and persistent under tropical conditions. While used perhaps most extensively as a soiling crop, cut and fed green in feeding racks in the corral or barn, it has proved to be valuable as well for grazing under a system of proper pasture management (7).[3]

In pastures Napier grass is usually allowed to grow until it has reached a height of from 5 to 8 feet before grazing is permitted. Continuous grazing is then practiced or, if a rotational system is used, one paddock is grazed for several months without rest. Due to the size of the grass when cattle are turned in, there is a considerable tramping down of coarse stalks with a consequent loss or waste of forage.

An alternative scheme is to pasture early and often, never allowing the plants to produce coarse woody stalks which develop when maturity is approached. All of the forage may then be palatable and there is little waste. The quality of forage is therefore higher, but the stand may be seriously injured when the plants are not allowed to maintain enough top growth so that a strong crown and root system can be developed.

When used as a soiling crop, various cutting rotations are employed, from harvesting the crop as often as every 30 days to cutting as infrequently as every 4 or 5 months. Whether used for pasture or as a soiling crop then, it appeared evident that a study of the effect of cutting treatment upon the yield and composition of forage as well as the persistence of stand was highly important.

Paterson (2, 3), working in Trinidad, found that when Napier grass was cut at the age of 4, 8, and 12 weeks for a period of 48 weeks, the 12-week cutting rotation gave the highest green forage and dry matter yields. The protein and ash percentages decreased with an increase in the age of the plant. The 12-week cutting rotation was recommended on the basis of forage yields, nutritive value, and persistence of stand.

Later studies on the frequency of cutting by Paterson (4, 5) included, besides Napier grass, several other of the large tropical forage grasses and harvests were made every 45, 90, 120, and 180 days. In general, the longer the cutting rotation up to 6 months, the greater were the yields. The height of cutting as well as the period between harvests influenced the regeneration habit of the ratoon crops. Root

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[3]Figures in parenthesis refer to "Literature Cited", p. 273.

and tiller examinations showed that the short cutting rotations resulted in less vigorous stools and decreased root development. Paterson suggested that a cutting rotation of approximately 3 months and herbage cut from 6 to 10 inches above the ground resulted generally in rapid ratooning, multiple tillering, and a strong stool development. Yields of Napier grass (elephant grass) were greatly reduced by an infestation of a fungus, *Helminthosporium* spp.

In the Philippine Islands, Villegas (6) found that the productive life span of Napier grass cut every month at a height of 120 cm was about 3½ years. Joachim and Ponditteskere (1), after studying manuring and frequency of cutting of Napier grass, recommended a 6-week cutting rotation with a nitrogen application after each cutting.

EXPERIMENTAL

The object of the experiment reported here was to study the effect of the frequency of cutting Napier grass on the total forage, palatability of forage, chemical composition, and growth behavior under Hawaiian conditions.

A field experiment, laid out on the University of Hawaii farm, included five frequency of cutting treatments with eight replications arranged in randomized blocks. Each plot consisted of four rows 4 feet apart and 34 feet long. The whole area was planted uniformly to a vigorous strain of Napier grass on November 13, 1934, using stem cuttings with at least two eyes per cutting, spaced 2 feet apart in the row. The plant crop of all plots was harvested uniformly on February 19, 1935, after approximately 3 months of growth, and from this date the frequency of cutting experiment began. The cutting treatments were harvested every 6, 8, 10, 12, and 14 weeks for the duration of the experiment. The experiment was terminated on November 23, 1937, 144 weeks later.

CULTURAL METHODS

All plots received the same total annual application of a complete fertilizer including 180 pounds N, 72 pounds P_2O_5, and 48 pounds K_2O per acre. This amounted to 1,200 pounds of mixed fertilizer per acre per year, an equal portion of which (for any one cutting treatment) was applied after each harvest. The plots cut frequently had more applications per year, but all plots had the same total application.

Yields decreased sharply in spite of this fertilizer application so after March 16, 1937, the annual application was increased to 300 pounds N, 150 pounds P_2O_5 and 150 pounds K_2O, or a total application per acre of nearly 2,000 pounds of complete fertilizer per year.

Weeds were kept out by hand hoeing and the field was irrigated when necessary.

HARVESTING

All plots were cut by hand with cane knives, cutting to 2 or 3 inches above the ground level and border rows were removed before plot weights were taken. Green weights were recorded in the field directly after the plots were cut and samples were taken to be used later for the determination of moisture, chemical composition, and relative palatability.

RESULTS

FORAGE YIELDS

A summary of total yields of green and oven-dry forage, as well as the percentage of palatable material, for all cutting frequencies for the duration of the experiment is given in Table 1.

TABLE 1.—*Summary of forage yields and percentage palatability of Napier grass for duration of experiment (144 weeks).*

Cutting frequency	Green weight, tons per acre*	Oven-dry weight, tons per acre†	Average percentage palatable forage
6 weeks	177.66	22.28	100
8 weeks	230.41	33.37	89
10 weeks	250.65	39.16	68
12 weeks	280.65	47.84	52
14 weeks	271.42	53.76	40

*A difference in treatment mean yields greater than 22.79 tons per acre is necessary for significance for a probability of 5%.

†A difference in treatment mean yields greater than 3.85 tons per acre is necessary for significance for a probability of 5%. At the 1% point a difference of 5.19 tons per acre is necessary

Analyses of variance of both green forage and oven-dry forage yields showed that differences due to cutting treatment were highly significant. When the mean yields (oven-dry weights) of the various cutting treatments for the duration of the experiment were compared, it was found that within the range of cutting frequencies used, the longer the period between harvests, the greater was the yield of forage. The following significant order of yields of the different cutting frequencies existed even at the 1% point of probability: 14-weeks > 12-weeks > 10-weeks > 8-weeks > 6-weeks. These yield results confirm those obtained by Paterson (2, 3, 4) from the standpoint of effect of cutting treatment. The actual yields, however, were much higher than those obtained in Trinidad, approaching what Paterson has suggested as the possible maximum yield of a forage crop estimated at 20 tons of oven-dry forage per acre per annum (4).

When the yield data from successive harvests were examined, it was found that there was a sharp decline in forage production following the first ratoon crop. In spite of continued use of a liberal fertilizer application throughout the course of the experiment, the high initial yields were not maintained. This is very likely due to both the large quantities of nutrients removed from the soil and the effect of cutting on this rapidly growing, vigorous grass under tropical conditions. The trend in reduction in yield following initial cuttings is shown graphically in Fig. 1. After the first sharp decline, yields were maintained at a fairly constant level for the remainder of the experiment. The slight rise in yields at 120 weeks was no doubt caused by the increase in fertilizer applications made previous to these cuttings. (See section on cultural methods.)

QUALITY OF FORAGE

Samples of the whole forage were divided into palatable and unpalatable portions at the time green weights were recorded. The arbitrary division used was that of including in the palatable portion all

leaves and that part of the plant above and including the fifth visible ligule from the tip of the culm. The remainder or stemmy portion was called unpalatable. Feeding observations using whole plants had previously shown that this was a fairly accurate measure of palatability. It is fully recognized, however, that varying amounts of this coarse stemmy material might be palatable, depending upon whether the grass was fed whole or finely chopped, as well as the season of the year, the fertilizer used, and other factors. This mechanical division did give, however, a crude basis at least for comparing the relative amounts of palatable and unpalatable forage produced as a result of

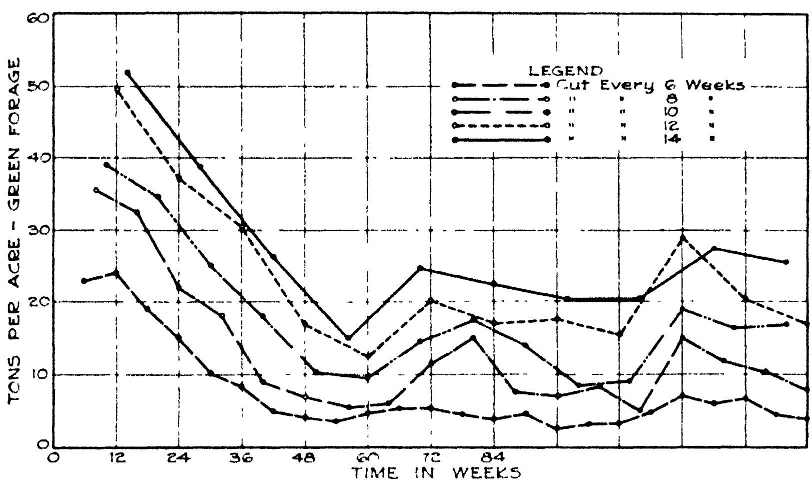

FIG. 1.—Yields of green forage in successive harvests of Napier grass under different cutting rotations.

the various cutting treatments. The average percentages of palatable portions of the total forage are given in Table 1, while the total yields of palatable and unpalatable forage as affected by cutting treatment are illustrated graphically in Fig. 2. The data indicate that palatability decreases rapidly as the cutting interval is increased.

CHEMICAL COMPOSITION

From samples obtained at each date of harvest, analyses of certain constituents were made on both the palatable and unpalatable portions of forage. The results are presented in summary form in Table 2.

Protein. Many dairymen and ranchers depend so largely upon green roughage for their principal feed that the protein content of forage becomes of considerable importance. An estimate of the protein produced per acre for the various cutting treatments is given in Table 3.

While there was no correlation between the yield of protein in the whole forage and cutting intervals, that fraction of the total amount produced which was present in the palatable portion of forage decreased considerably as the periods between cuttings increased. There appeared to be an especially marked drop between the 8- and 10-

TABLE 2.—*Average chemical composition of Napier grass on over-dry basis.*

Cutting frequency, weeks	Crude protein, %	Ether extract, %	Crude fiber, %	Ash, %	N-free extract, %	P_2O_5, %	CaO, %
			In Whole Forage				
6	7.90	2.19	28.81	19.24	41.86	1.68	0.646
8	5.86	1.93	32.32	18.20	41.69	1.57	0.600
10	5.19	1.78	34.72	16.42	41.89	1.36	0.456
12	4.21	1.78	36.65	15.06	42.29	1.33	0.416
14	3.75	1.58	39.33	12.98	42.56	1.08	0.366
			In Palatable Portion				
6	7.90	2.19	28.81	19.24	41.86	1.68	0.646
8	6.94	1.96	30.66	19.15	41.29	1.57	0.600
10	5.99	1.93	32.00	17.63	42.46	0.92	0.419
12	5.88	1.95	32.56	17.07	42.54	1.34	0.445
14	5.64	2.00	33.87	15.43	43.06	0.95	0.532
			In Unpalatable Portion				
6	—	—	—	—	—	—	—
8	2.62	1.32	40.64	13.34	42.08	—	—
10	2.29	1.26	42.79	11.08	42.62	1.30	0.193
12	2.12	1.26	41.90	11.44	43.27	1.38	0.242
14	1.87	1.32	44.04	10.28	42.50	1.17	0.238

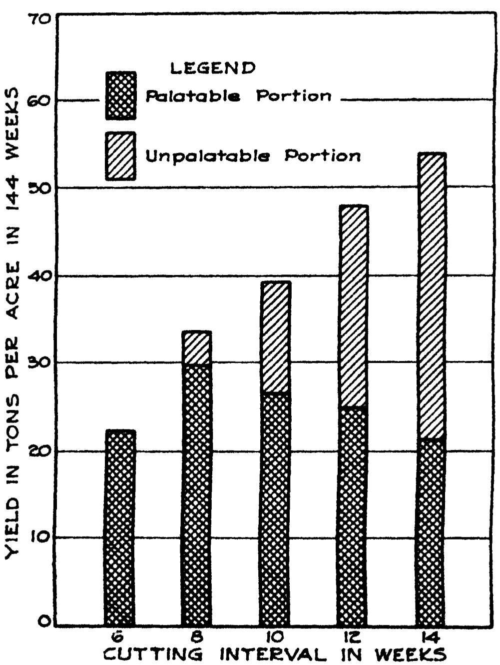

FIG. 2.—Oven-dry yields of palatable, unpalatable, and total Napier grass forage as affected by cutting frequency.

week cutting intervals. The steady drop in protein present in the palatable portion of forage from the 8-week to 14-week cutting intervals was due to the combined effect of the decrease in percentage protein and proportion of palatable portion as the cutting intervals were increased.

There was a marked increase in the amount of protein produced in the unpalatable portion as the cutting interval was increased.

The 8-week cutting interval gave the best results from the standpoint of yield of protein in the whole forage as well as in the palatable portion.

The percentage protein content decreased steadily in both palatable and

unpalatable portions as the cutting intervals were increased. The percentage composition of protein in the palatable portion was about three times as large as that of the unpalatable portion.

TABLE 3.—*Average number of stalks per hill and yield of protein per acre in all cutting treatments for duration of experiment.*

Cutting interval, weeks	Stalks per hill	Pounds of protein per acre		
		Whole forage	Palatable portion	Unpalatable portion
6	13.4*	3,494	3,494	0
8	23.5	4,040	3,726	314
10	25.0	3,440	2,730	714
12	26.6	3,834	2,848	986
14	23.0	3,500	2,289	1,212

*The number of new shoots coming up after harvest was always large, but most of these never attained such size as to be considered a stalk in the hill.

Crude fiber.—From Table 2 it is shown that the crude fiber content of the plant increased with the age at which it was harvested. Forage cut at 14 weeks of age had a crude fiber content nearly 40% higher than that cut at 6 weeks. The crude fiber content was materially higher in the unpalatable portion than in the palatable portion of forage for all cutting treatments.

Total ash.—The percentage of ash as shown in Table 2 decreased markedly as the plant matured, ranging from 19.24% in the whole forage at 6 weeks of age to 12.98% at 14 weeks. The palatable forage had a materially higher percentage of ash than did the unpalatable portions.

The data on chemical analyses compare favorably with the results obtained by other investigators (1, 2, 3).

GROWTH BEHAVIOR

The plant crop of Napier grass produced in 70 to 100 days after planting stem cuttings is tall, rank, and succulent. Relatively few stalks per hill are produced, the growth is rapid, the protein content in percentage is fairly high, moisture content is high, and the whole stalks are relatively palatable unless the plants have begun to bloom (7). After the plant crop is harvested, a vigorous stooling or tillering takes place and the development in succeeding ratoon crops is determined to a considerable extent by the severity of cutting treatment.

As has been explained by Paterson (4), Napier grass regenerates after cutting by two methods, either terminal or bud development. In young tillers, if the grass is not cut too close to the ground, the growing point of each tiller is not cut off and continued development produces new foliage. In this experiment the grass was always cut just above the ground level so that, with the exception of the 6-week cutting rotation, the regeneration must have come mainly from the development of dormant buds at the base of the tillers. This type of regeneration would tend to make the crown spread out more,

but recovery would probably be less rapid than if terminal regeneration could take place.

Under pasture conditions, where the plants are allowed to become somewhat mature and stemmy before grazing is started, much of the regeneration is confined to the terminal portion of the stem, a tuft of leaves developing at the nodes just below the place where the tip of a stalk has been chewed off.

Counts were made of the number of stalks per hill at each harvest. At the end of the experimental period these counts were averaged with the results indicated in Table 3.

The number of stalks per hill did not vary greatly with the exceptions of those produced by the 6-week cutting treatment. The grass on these plots started to recover very rapidly, but subsequent growth was slow and feeble. There was also an indication of a falling off in the number of tillers in the 14-week cutting treatment which may have been brought about as a result of excessive competition for moisture, nutrients, and sunlight.

Greater tillering, better recovery, and more vigorous growth were found on the plots cut at intervals of 8 weeks or more. Sufficient leaf area had been allowed to develop so that enough carbohydrates were synthesized and translocated to build up a strong crown and root system.

With an increase in age of the stand there was a tendency for plants to spread out by tillers and rhizomes from the original hill. This growth habit caused the appearance of bare spots in the center of many stools and it appeared that the plant might be dying. Examination of the underground parts of many such plants showed that the crown was alive in the center of the hill but was in a dormant condition. The grass cut at frequent intervals spread much less by rhizomes than did the grass cut less frequently.

It has been known for some time that too frequent cutting is disasterous to the highest production and persistence of many temperate zone forage species. The data presented have indicated that cutting treatment is of no less importance with tropical grasses under conditions of year-round rapid growth. It is essential then to find the proper balance between high protein, high mineral content, and high palatability, on the one hand, and high yield of dry matter and persistence, on the other. The results of this investigation have shown high forage yields, high palatability, and relatively high protein production in the grass cut every 8 weeks. The stand was satisfactory at the close of the experiment. Where fertilizers are applied after each harvest, a cutting rotation of about 8 weeks would therefore appear to be desirable. As there was an indication of seasonal effect on yields, it might be of advantage to increase the interval between cuttings to 10 weeks during the cooler winter months.

SUMMARY AND CONCLUSIONS

An experiment designed to determine the effect of frequency of cutting on the growth and chemical composition of Napier grass is described.

In production of forage an increase in the interval between harvests resulted in a higher total yield. Dry matter yields arranged themselves in this decreasing order: 14-week cutting interval > 12-week > 10-week > 8-week > 6-week.

There was some indication of a seasonal effect on forage yields.

The greatest amount of palatable forage was produced by cutting every 8 weeks .(An arbitrary mechanical division of forage into palatable and unpalatable portions was used.) The greatest amount of protein in the palatable portion of forage was produced by the grass cut at 6 and 8 weeks of age.

The percentage of palatable forage as well as the percentages of protein and ash (including phosphorus and calcium) decreased with an increase in the age of the plants.

The crude fiber percentage increased with an increase in the interval between cuttings.

The grass cut every 6 weeks was handicapped by poor recovery after each harvest, depleted stand, and greater weed competition.

When the factors of high yield, quality of forage, and persistence of stand are all considered, it would appear desirable under Hawaiian conditions to cut Napier grass every 8 weeks. It also seems likely that because of the seasonal effect, impossible to analyze adequately in the experiment described, a 10-week cutting interval might be used to advantage during the winter months when growth is slower. Such treatment should insure maximum yields of palatable, high quality green roughage, extending over a period of years without the necessity of replanting.

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INFLORESCENCE VARIATIONS IN BUFFALO GRASS, *BUCHLOE DACTYLOIDES*[1]

LEON E. WENGER[2]

SEVERAL interesting variations in the inflorescence of buffalo grass were noted during the summer and fall of 1939 in plants grown in the buffalo grass breeding nursery at the Fort Hays Experiment Station, Hays, Kansas.

Buffalo grass is largely dioecious, although a small percentage of the individuals are monoecious. Counts made in the breeding nursery during the last two years have shown that approximately 7% of the bulk population are monoecious, while 51% are pistillate and 42% are staminate.

FIG. 1.—Spikelet types occurring in 3-i Buffalo grass. *Left*, normal pistillate spikelet (1 floret); *center*, abnormal spikelet resembling a staminate spikelet but containing two pistillate florets (no stamens); *right*, normal staminate spikelet (2 florets).

The staminate inflorescence of buffalo grass, consisting usually of two or three short spikes, is borne on an erect slender culm protruding above the foliage. The pistillate inflorescence, consisting of two or three extremely short spikes, referred to commonly as burs, is normally produced rather obscurely on short culms among the leaves and is further hidden by being partially enveloped in the somewhat inflated sheaths of the upper leaves. The staminate spikelet has two flowers, whereas the pistillate spikelet normally has but one flower (Fig. 1).

[1]Contribution of Fort Hays Branch of the Kansas Agricultural Experiment Station, Hays, Kansas, in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Contribution number 29. Received for publication January 26, 1940.

[2]Forage Crops Specialist, Fort Hays Branch Agricultural Experiment Station, and Agent, U. S. Dept. of Agriculture, in charge of forage crop investigations.

Buffalo grass with perfect flowers was noted first in 1938 at College Station, Tex., by Hensel,[8] and has since been observed at this station. This phenomenal character was noted here in a staminate plant, but in this instance not more than 2% of the total number of inflorescences contained perfect flowers. A few of the other inflorescences on this plant produced spikelets containing both staminate and pistillate flowers. Twelve seeds were produced in 1939 under open-pollinated conditions in the nursery and upon being planted in the greenhouse eight of these seeds germinated. The pollen from this plant is also known to be functional because in a cross where it was used a good amount of viable seed was produced.

FIG. 2.—Variations in the inflorescence of buffalo grass noted in selection 3-i. Externally this appears to be a staminate inflorescence, but (1) shows a spikelet containing two pistillate florets, (2) shows a hermaphroditic spikelet containing a pistillate floret and a staminate floret, and (3) shows a normal staminate spikelet containing two staminate florets.

Other striking variations in the flowering habits of buffalo grass were noted in a pistillate plant selected for its tall seed-stalk character. This plant, started in 1936 from seed obtained from southern Oklahoma, produced only normal-appearing flower types in 1937 and 1938. On July 12, 1939, however, it was noted that a few off-type inflorescences were being produced on an increase planting of this selection where certain cultural treatments, namely, height and time of clipping as affecting the height and yield of seed, were being studied. Some of the variants contained both anthers and stigmas, but the florets upon being examined were found to be imperfect. The majority of these abnormal types appeared externally to be staminate. Close examination, however, disclosed four distinct variations. A few of the inflorescences contained staminate flowers in well-formed two-

[8]HENSEL, R. L. Perfect-flowered Buffalo grass, *Buchloe dactyloides*. Jour. Amer. Soc. Agron., 30:1043–1044. 1938.

flowered spikelets, but in these instances the spikes were much shortened and closely grouped. Some contained pistillate flowers in

FIG. 3.—Two types of inflorescences produced on buffalo grass selection 15-9-38. *Left*, normal pistillate inflorescence. *Right*, hermaphroditic inflorescence with peduncle and rachis elongated. Some of the lower spikelets produced only stamens, while some of the upper spikelets produced only seed.

malformed two-flowered spikelets (Fig. 1) and some contained spikelets with one pistillate and one staminate flower. Still other inflorescences had spikelets with all three variations (Fig. 2). Another type of variation was noted in pistillate inflorescences in which the rachis and peduncle were elongated thereby resulting in long open burs with the entire inflorescence extending beyond the upper leaves.

Whether the variations in this plant were the result of the cultural treatment, of the season, or of some genetic disturbance has not been determined. Possibly they were the result of a combination of all factors. Certainly the sex character in buffalo grass is complex and definitely unstable. No seed was produced in the off-type inflorescences, supposedly because of the excessively high temperatures which occurred simultaneously with anthesis. Very little seed was produced in the normal inflorescences even though these out-numbered the off-types many times, doutbless because of the same conditions.

This plant entered drouth dormancy during the latter part of July due to adverse conditions, but when temporarily revived by rains and cool weather during the week of August 7, it started to send out new inflorescences, some of which exhibited the earlier mentioned variations.

Still other variations were noted in a third selection during early September. In this instance the off-type inflorescences appeared in an increase planting which had been established by rooted nodes, but could not be found in the original pistillate plant which was still growing where originally set out in 1938 only a little distance away. The off-type flowering structures appeared externally to be staminate because they were produced on greatly elongated culms well above the foliage. Examination showed that these variations were of two types. In one the culm, peduncle, and rachis were all much elongated and the inflorescence contained only pistillate spikelets. In the other, aside from the various parts all being much elongated, the lower spikelets contained staminate florets and the upper spikelets contained pistillate florets. (See Fig. 3.) Seed was produced in both types of inflorescences. These variations appear to be the result of changes in the environment. inasmuch as the undisturbed parent clone produced neither variation in either 1938 or 1939.

It is of interest to note that all of the above-described variations occurred in dioecious plants and that the common tendency was for each plant to try and compensate for its sex deficiency by either producing flowering structures containing organs of the opposite sex or by producing structures that roughly assumed the form of the deficient sex inflorescence.

EFFECTS OF GRAZING UPON BUNCH WHEAT GRASS[1]

W. R. HANSON AND L. A. STODDART[2]

DURING the past decade much attention has been given to the great range lands of the West. These lands are inherently low in productivity because of aridity. Abnormal drought and constantly heavy use by livestock have caused the vegetation over much of the area to become greatly depleted. The forage has decreased in quantity, but more serious in many cases is the decrease in quality. Valuable species have been replaced by less valuable or even worthless ones. Because of the serious nature of these changes a number of ecological studies have been conducted on native grass to determine the reason for range deterioration.

The studies were made during the summer of 1938 in southern Cache Valley, Utah. The observed range occupies the benches and foothills above the more moist valley floor and is roughly comparable to the northern intermountain grasslands.

Originally bunch wheat grasses, *Agropyron inerme* (Scribn. and Smith) Rydb. and *Agropyron spicatum* (Pursh) Scribn. and Smith, were apparently dominant on the benches and alluvial fans.[3] Sagebrush, *Artemisia tridentata* Nutt., was generally subdominant to the grass but dominated the vegetation on some exposed slopes.

The present abundance of sagebrush on the heavily-grazed benchland and the sparsity of bunch wheat grass suggest invasion of sagebrush into climax grassland. Bunch wheat grass is scarce or lacking in many places along the benches. That this grass had been dominant is evidenced by the presence of an almost pure stand of wheatgrass on one side of a range division fence and almost pure sagebrush or sagebrush-weed on the other (Fig. 1). On parts of the range where grazing has been more moderate wheatgrass is still abundant, but it has undergone considerable reduction in number and size of plants.

The question naturally arises as to the causes within the plant which led to the disappearance or severe reduction of the wheatgrasses under current grazing practices. Investigators have recognized the importance of food accumulations in the economy of the plant; but other than the work done by McCarty (7, 8, 9)[4] and Aldous (1), little investigation of carbohydrate relationships of range forage species has been undertaken. This phase of the problem has to do with the permanence of the climax plants and the sustained yield of forage from year to year. Closely allied are the relationships of underground parts to longevity and forage yield. Because roots are less apparent and more difficult to study, they are often neglected in the consideration of a plant.

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[1]Contribution of the Range Management Department, Utah Agricultural Experiment Station, Logan, Utah. Received for publication January 30, 1940.

[2]Graduate Research Fellow and Research Professor of Range Management, respectively.

[3]*Agropyron spicatum* (Pursh) Scribn. and Smith, and *A. inerme* (Scribn. and Smith) Rydb. are differentiated by Hitchcock only by the presence or absence of awns. In some works *A. inerme* is considered as a sub-species.

[4]Figures in parenthesis refer to "Literature Cited", p. 288.

A sustained stand depends partly upon longevity of the plants and partly upon seed production and the subsequent establishment of the plants as seedlings. Seed crop, in turn, depends upon plant vigor, which in turn depends upon a sturdy root system and a store of carbohydrates to initiate strong growth in the spring.

FIG. 1.—Protected and overgrazed wheat grass range.

REVIEW OF LITERATURE

Clements, Weaver, and Hanson (6) established the fact that the kind and condition of the root system are the primary factors determining success in ecesis and subsequent competition. Weaver (12) pointed out that most root systems of prairie grasses deteriorate under heavy grazing and are less able to cope with drought and the rigors of winter.

Biswell and Weaver (4) studied the effect of frequent clippings upon the roots and tops of some prairie grasses. The size of both tops and roots was greatly reduced by this practice. Clipped plants failed to produce new rhizomes, and many old ones died. The length of roots was greatly decreased, and the relative production of roots was more greatly reduced than that of tops. The average weight of roots of clipped plants was 10.1% of the controls.

Flory and Trussel, cited by Calkins (5), studied the root habits of several southwestern grasses in their relation to soil conservation. The root systems of all these grasses were markedly decreased under heavy grazing.

McCarty (9) studied the march of carbohydrates throughout the growth of *Bromus carinatus*, *Elymus ambiguous*, and *Muhlenbergia gracilis*. Starch and sugars were found to be the most potent stored foods. In general, the starch and sugar content of roots and stem bases reached a maximum immediately following current seasonal growth, declined slightly during the rest period, and reached the minimum during the formative stages of shoot development. For incipient growth, both root and shoot, the plant depends completely upon the stored carbohydrate for energy and building material. The plant soon reaches the stage where it manufactures carbohydrate, but this carbohydrate is used by body processes as fast as it is manufactured. At the point where growth rate begins to decline, storage begins.

The limited studies that have been made show conclusively that reduction of the photosynthetic area during the growth period decreases the reserve of carbohydrate stored in the root and stem bases; and that this, in turn, reduces subsequent vigor and yield (1, 7, 10).

STUDIES ON ROOT DEVELOPMENT

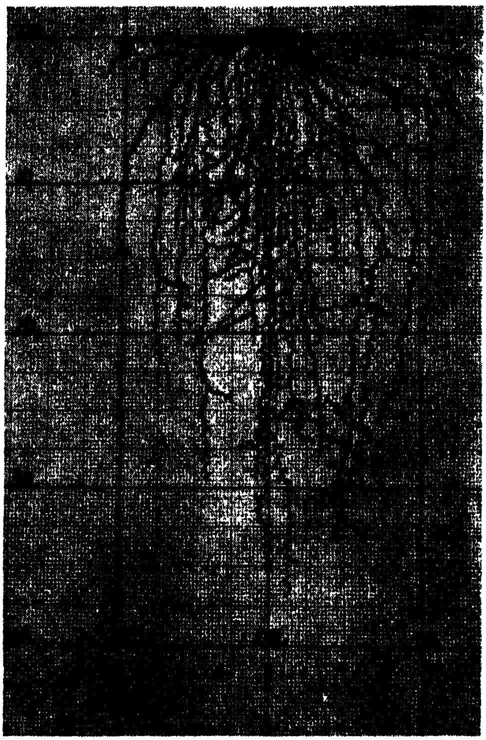

FIG. 2.—A representative root system of *Agropyron inerme*.

To determine the normal growth of the roots of *Agropyron inerme* and the effect of grazing upon the root system, studies were conducted along a division fence between a pasture and a protected field. Grazing was heavy on the one side and climax grasses were obviously depleted in both number and size. On the other side was approximately climax wheatgrass stand, grazed only in the autumn after cultivated crops had been harvested.

The roots were studied as dug from the walls of an excavation by means of an ice pick and later were charted (Fig. 2). The root system of undisturbed *Agropyron inerme* occupied the upper soil layers very effectively; the finer rootlets and root hairs, not shown in the chart, completely permeating the soil. Extending from the crown were numerous horizontal roots. The main body of roots, however, grew downward and fed in deep soil layers.

Maximum depth of the roots was fairly constant in each area, some roots penetrating to depths of over 180 cm, but lateral spread varied with available space. In the climax stand the root system of each plant contacted and, to a limited degree, intermingled with that of its neighbors. (See Fig. 3.)

In order to compare the root weight of normal plants with their top weight unit volumes of soil were collected under the plants, and the roots washed out by use of fine screens. By multiplying average volume of soil permeated by a plant by the average weight of living grass roots within that soil an estimate of the weight of the entire root system was obtained.

Most of the plant weight was actually underground. An average of estimations showed the underground parts to weigh about 13 times as much as the herbage. This estimation did not include root hairs and finer rootlets which passed through the screen during washing. Hence, root weight might have been appreciably greater had all root parts been included.

FIG. 3.—Bisect through climax stand of *Agropyron inerme*. Br, *Bromus tectorum*; Ag, *Agropyron inerme*; H, *Helianthella uniflora*.

To study the effects of grazing upon the roots, six plants were selected to represent grazed land and six protected land. A small trench was dug next to each plant and the main roots and branches were followed to their tips (Table 1). Maximum depth of the grass roots in this location was somewhat limited by a shallow soil; nevertheless, the root systems of grazed plants were unable to utilize the full depth of soil. Though average depth of the roots was 65 cm on protected

TABLE 1.—*Average maximum lateral spread and depth of roots of Agropyron inerme.*

Plant No.	Protected		Grazed	
	Depth, cm	Lateral spread, cm	Depth, cm	Lateral spread, cm
1	71	38	46	41
2	61	33	43	69
3	66	46	41	33
4	61	36	46	46
5	69	43	46	48
6	63	43	43	38
Average......	65	40	44	46

plants as compared to 44 cm on grazed plants, the lateral spread did not appear to be materially changed.

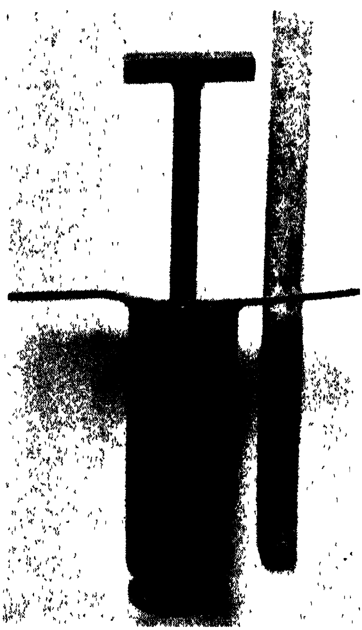

FIG. 4.—Tool for sampling root weight per unit volume of soil.

To determine the effect of grazing upon the root weight, a sampling tool was devised (Fig. 4). It consisted of a steel cylinder with a cutting edge and was fitted with a plunger. The handle of the plunger was marked to correspond to a given volume in the cylinder below the plunger.

A trench was dug alongside representative bunches of grass. The herbage was cut off. The sampler was placed over the center of the bunch and forced vertically into the soil until the mark on the handle appeared, which designated the desired volume enclosed within the cylinder. The soil was then cut away from around the cylinder and the enclosed soil and root mass severed from that below by a sharp knife. The plunger was used to remove the soil block to a paper bag. Samples were taken below the crown at levels of 0 to 15 cm, 15 to 30 cm, 30 to 45 cm, and 45 to 60 cm.

The soil blocks were taken into the laboratory where the soil was removed by water. Each block was placed in a fine-screen strainer and washed under the tap. When the soil was removed, the live grass roots were separated from the dead ones, other roots, and foreign material. This separation is a difficult process and was accomplished by washing, floating, and hand picking. Dead roots and live roots are easily distinguished only after some decay has taken place resulting in a color change. For this reason a few roots dead only a short period of time may have been included among the living roots. The grass roots were oven-dried and weighed, these weights being taken as an index of root development at a given depth.

The average index figure for grazed plants was 4.22 grams of roots per cubic decimeter, as compared to 25.85 grams per cubic decimeter for protected plants (Table 2). Therefore, the root development in the soil below protected plants was more than six times as great as below heavily grazed plants. Further, many root systems of heavily grazed grass plants failed to extend beyond a depth of 45 cm, while all protected plants had good root volume at and below this depth.

TABLE 2.—*Weights of Agropyron inerme roots from grazed and protected areas in grams per cubic decimeter of soil at various depths below the crown.*

Sample No.	Depth below the crown, grams				
	0–15 cm	15–30 cm	30–45 cm	45–60 cm	Total
	Plants from Heavily Grazed Area				
1	4.18	0.14	0.07	0.07	4.48
2	4.11	0.19	0.09	0.02	4.41
3	5.04	0.07	0.06	0.04	5.21
4	4.86	0.07	0.05	0.02	5.00
5	2.99	0.07	0.01	0.11	3.18
6	2.76	0.14	0.02	0.00	2.92
7	3.36	0.16	0.05	0.00	3.57
8	4.81	0.09	0.02	0.04	4.96
Average.....	4.01	0.12	0.05	0.04	4.22
	Plants from Protected Area				
1	14.11	1.45	0.40	0.16	16.12
2	43.96	0.98	0.47	0.19	45.60
3	14.16	1.33	0.47	0.26	16.22
4	49.76	1.73	0.26	0.19	51.94
5	23.36	0.47	0.35	0.16	24.34
6	9.58	1.19	0.30	0.09	11.16
7	18.92	1.54	0.91	0.26	21.63
8	17.12	1.80	0.70	0.18	19.80
Average.....	23.87	1.31	0.48	0.19	25.85

STUDIES ON HERBAGE PRODUCTION

To study the effect of grazing upon herbage production, a system of quadrats was laid out. Along the fence dividing the grazed and protected area a strip 20 meters wide and 200 meters long was delimited and subdivided into transects 2 meters wide, lying at right angles to the fence. Four of these were chosen for study. Each was divided into four square-meter quadrats. Within each transect two quadrats were chosen on the protected area and two on the grazed area. All choices were made at random. The basal area of *Agropyron inerme* was measured by the use of a pantograph. Average height and number of stalks per square meter were determined. The data from the measurements are summarized in Table 3.

TABLE 3.—*Basal area, height, and average number of stalks of Agropyron inerme under grazing and protection.*

Treatment	Av. basal area per sq. meter of ground, sq. cm.	Extremes, sq. cm.	Average height, cm.	Average no. of stalks per sq. meter
Grazed......	56.8	0–275	51	11.4
Protected....	538.5	0–1767	66.5	123.2

There was a very marked reduction in the above-ground parts of wheatgrass accompanying heavy grazing, as shown by a decrease in basal area, height, and number of seed stalks.

STUDIES ON SEED PRODUCTION AND GERMINATION

Seed samples for germination were collected from two locations, some from grazed plants and some from ungrazed. At the first location, eight samples of 10 heads each were collected in the near proximity of each of the plants studied for root production. The mature seeds were separated from the empty florets so that germination tests included only the filled seeds.

Duplicate germination tests were conducted in which moistened blotting paper in petri dishes was used as a planting medium. The number germinated was counted after 5 days and each second day thereafter until the 15th day, after which no germination took place. Conditions adhered to were those given by the *Association of Official Seed Analysts* (3).

Though seeds from grazed plants had a final germination average of 79.7% compared to 73.2% from ungrazed plants, the difference is not significant. At 5 days the germinations averaged 55.6 and 44.9%, respectively.

The second set of samples was obtained from the areas laid out in quadrats for the herbage study. All heads from each of 15-sample quadrats were collected. Percentage germination was determined as with the previous samples.

There was, as in the first test, no significant difference between germination of seeds from the grazed area and the protected, either at 5 days or at 15 days. The germination of seed from ungrazed plants was 21.3% at 5 days and 64.8% after 15 days (complete germination), whereas germination of seed from grazed plants was 21.3% at 5 days and 62.2% after 15 days.

However, Table 4 presents some important differences. The potentiality for reproduction by seed is many times greater for protected plants. The proportion of the florets that matured on protected plants exceeded that on the grazed area by 14.9% Also, the viable seeds per square meter of ground were almost 50 times as numerous on the protected area.

STUDIES ON FOOD RESERVES IN ROOTS AND STEM BASES

The area laid out for herbage studies was used to obtain material for carbohydrate determinations. Four plants were selected from each of the transects, two being taken from each side of the fence. Those from the one side were protected plants, while those from the other were plants from a pasture grazed at an intensity of 7 acres per animal for 5 months. Since forage was more plentiful than usual, the grass plants were not grazed until after seed maturity. It is assumed, therefore, that any effect found upon storage of carbohydrate is chiefly attributable to the grazing of previous years.

Each plant was dug, freed of soil by means of a stiff brush, and the roots and stem bases clipped into small pieces. This material was placed in hot 95% alcohol for preservation until analyses were made.

TABLE 4.—*Seed heads, filled florets, percentage germination, and viable seeds produced on grazed and protected stands of Agropyron inerme.*

Plot No.	No. of heads per sq. meter	Filled florets		Germination 15 days, %	No. of viable seeds per sq. meter
		Per sq. meter	%		
		Grazed			
1	14.7	33.0	24.0	83.4	27.5
2	1.5	4.5	25.0	82.5	3.7
3	1.5	2.8	13.8	45.0	1.3
4	12.8	25.5	27.0	45.0	11.5
5	6.0	27.9	30.2	86.1	24.0
6	5.5	24.8	31.5	67.4	16.7
7	8.0	21.2	15.6	52.0	11.0
8	5.8	17.2	24.4	36.7	6.3
Average	7.1	19.6	23.9	62.2	12.2
		Protected			
1	90.2	483.7	25.4	60.0	290.2
2	156.8	1053.4	39.8	81.5	858.5
3	123.5	968.1	42.6	74.5	721.2
4	63.2	582.5	46.7	76.0	442.7
5	174.2	1094.3	27.8	45.5	542.2
6	92.0	817.0	45.0	75.5	616.8
7	160.5	2099.3	47.2	46.5	976.2
8	102.5	682.6	36.2	58.5	399.3
Average	120.4	972.6	38.8	64.8	630.2

The official methods (2) were used in the preparation and analysis of samples with the following exceptions: The reducing sugar was determined by the Shaffer and Hartman method (11); starch was hydrolysed by the use of saliva, as described by McCarty (7).[5] The carbohydrate fractions were computed in percent of moisture-free weight of the sample.

Percentages of ash, sugar, starch, and hemicellulose in the samples taken are shown in Table 5. The ash content of the two treatments was not significantly different. The combined sugar and starch fractions were, however, significantly higher for the protected plants. Variance due to treatments (grazing and protection) was significantly greater than error, and therefore, the mean of the protected area was significantly greater than the grazed.

The means of the total carbohydrates, including hemicellulose, are not significantly different. The f value for between treatments is 3.829, while an f value of 4.96 is required for significance. The factor causing a smaller difference here is the presence of the hemicellulose. The hemicellulose fraction then does not differ significantly between protected and grazed plants.

[5]It has been suggested that substances dissolved by saliva are not necessarily starch, but this method is believed by the authors to give results sufficiently accurate for comparisons.

TABLE 5.—*Ash and carbohydrate content of roots and stem bases of Agropyron inerme from grazed and protected ranges.*

Sample No.	Ash content, %	Carbohydrate				
		Sugars, %	Starch, %	Sugar and starch, %	Hemicellulose, %	Total, %
			Grazed			
1 a	9.00	1.10	2.32	3.42	8.76	12.18
b		1.18	1.99	3.17	8.84	12.01
2 a	10.15	1.82	2.48	4.30	9.03	13.33
b		1.42	2.38	3.80	8.79	12.59
3 a	18.19	1.50	3.23	4.73	8.14	12.87
b		1.90	3.40	5.30	8.36	13.66
4 a	8.69	1.26	3.23	4.49	7.11	11.60
b		1.34	3.64	4.98	7.26	12.24
5 a	12.75	2.74	3.90	6.64	15.46	22.11
b		2.21	3.72	5.92	15.00	20.92
6 a	12.14	2.89	1.96	4.85	9.64	14.49
b		2.67	2.39	4.06	9.96	14.02
Average	11.82	1.84	2.89	4.64	9.70	14.33
			Protected			
1 a	7.88	2.30	4.11	6.41	16.01	22.42
b		2.03	3.94	5.97	14.40	20.37
2 a	11.59	2.03	4.07	6.10	12.63	18.73
b		1.91	3.82	5.73	12.05	17.78
3 a	13.04	8.24	2.89	11.13	8.36	19.49
b		7.75	2.89	10.64	8.54	19.18
4 a	7.88	2.50	3.60	6.10	9.47	15.57
b		2.74	3.54	6.28	10.00	16.28
5 a	8.05	2.70	3.94	6.64	9.02	15.66
b		2.55	3.77	6.32	9.12	15.44
6 a	9.71	2.30	4.60	6.90	9.63	16.53
b		2.33	3.97	6.30	9.45	16.75
Average	9.69	3.28	3.76	7.04	10.72	17.77

DISCUSSION AND CONCLUSIONS

Agropyron inerme is especially well-adapted to grow in the semi-arid range lands of the northern intermountain regions of the United States. Moisture is the prime limiting factor in plant growth in this region, and the water balance of the plant determines largely its ability to exist. The extensive root system of *Agropyron inerme*, which practically fills the soil sometimes to a depth of over 180 cm, normally supplies water at a rapid enough rate to sustain the water balance of the plant. The shallow roots take advantage of light rains and the deeper roots reach the subsoil moisture reserves. This efficient root system, along with an ability to grow rapidly when moisture is available and the power to produce seed abundantly, enables *Agropyron inerme* to maintain itself in a semi-arid habitat if undisturbed.

Yet, under intense grazing, it yields its dominant position which it so ably holds if undisturbed. This study shows that changes brought about by overgrazing seriously alter the power of the plant to thrive in an arid environment.

Besides mechanical injury, the immediate deleterious effect of heavy grazing is the reduction of the photosynthetic area. The food resulting from photosynthesis is required to repair and build tissue in both roots and herbage and as food for energy release. A store of carbohydrate is required to carry the plant through its more or less dormant period and then to supply food for root growth and incipient herbage growth. Herbage removal leads to shortage of stored food and, hence, to poor root production and weakened growth in spring.

Furthermore, one year was insufficient for the plants to regain their normal food supply. Plants which were ungrazed during the season that samples were taken but which had been heavily grazed in previous seasons showed a food reserve reduction of 19.4% compared to protected plants. The explanation seems to be one of food relationships. When re-growth began, the food supply was drawn upon to replace dead roots and to initiate herbage growth. Due to a shortage of food in previously grazed plants, normal vigor was not attained, and, even though the plants were undisturbed for one season, food manufacture was inadequate to sustain a normal root system and replenish the supply as well.

The marked reduction in depth, spread, and intensity of ramification of the roots of heavily grazed plants as compared to roots of protected ones was the natural result of herbage removal during growth. Stored carbohydrates are the base materials for the manufacture of proteins and the complex carbohydrates used in cell structure. A dearth of carbohydrate, therefore, would result in reduction of the root system. The effect of a reduction of the root system upon the water relations is evident. Plants with depleted root systems are more susceptible to drought injury.

Agropyron inerme produced an average of 630 viable seeds per square meter of ground when protected. The effects of heavy grazing brought about a reduction to 12 in the number of viable seeds produced, and therefore materially lessened the chance for reproduction. Germination of seed, however, is not affected by grazing and resultant weakening of the plant.

The cause of reduction in size and numbers of *Agropyron inerme* plants on heavily grazed ranges lies largely in the following sequence of factors: (a) Removal of the photosynthetic tissue resulting in a dearth of stored food in roots and stem bases, (b) a depletion of the root system and lack of vigor in the next year's plant, (c) the reduced root system and lack of vigor in the early season leaving the plant more susceptible to drought injury, (d) fewer viable seeds decreasing the possibility of reproduction. These results act cumulatively and depletion of the stand is progressive.

SUMMARY

Agropyron inerme was studied on range land in Cache Valley, Utah. Studies were made on protected and heavily grazed areas to compare root development, herbage and seed production, and content of sugar, starch, and hemicellulose in roots and stem bases.

The habits of growth of the roots of *Agropyron inerme* are well adapted to its habitat and insure the species a place as dominant in the area studied. The soil mass below normal plants was thoroughly permeated from a depth about 5 cm to as deep as 180 cm. Root weight was 13.1 times top weight.

The average weight of roots per cubic decimeter of soil was 25.85 grams on protected range and 4.22 grams on heavily grazed range, a reduction to about one-sixth the normal. Maximum depth of roots of grazed plants was materially reduced.

There was a very marked decrease in the above-ground parts of wheatgrass accompanying overgrazing as evidenced by reduced basal area, height, and number of seed stalks.

Germination tests of filled florets taken from protected and heavily grazed range showed no significant difference. On protected range 38.8% of the florets matured and on heavily grazed range 23.9% matured. There were 630.2 viable seeds per square meter of ground produced on protected range and 12.2 on the heavily grazed area.

Stem bases and roots of plants protected from heavy grazing in previous years contained 17.77% sugar and starch, while those of plants grazed heavily in previous years contained 14.33%. The hemicellulose content was not significantly different.

This study leads one to conclude that *Agropyron inerme* could have been dominant on much range land in Cache Valley where it is at present scarce or wanting, and general observations indicate that it was dominant. Sustained yield of *A. inerme* depends predominantly upon extent, intensity of ramification, and carbohydrate content of the root system. This study emphasizes the importance of controlled grazing.

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SOIL AND EROSION CHANGES ON THE DALHART SAND DUNE AREA[1]

LUTHER K. EBY AND CHARLES J. WHITFIELD[2]

IN the past few years, certain areas in the southern Great Plains have suffered from extreme wind erosion with the subsequent formation of sand dunes. In 1936, an experimental area was established in Dallam County, Texas, which is known as the Dalhart Sand Dune Area. This site, consisting of 2,000 acres, was selected as being typical of a large number of similarly wind-eroded areas. The results of studies dealing with the methods of stabilization and utilization of this sand dune area have been reported by Whitfield.[3] In April 1936, a Soil Conservation Service survey was made on this experimental area prior to treatment.[4] In August 1939, another survey was made on a portion of the area (925 acres) to obtain information of a specific nature as to the changes in soil and erosion that had occurred in the interval of about 3½ years.

Before examining these two surveys, it might be well to note in a general way the nature of the soils occurring on the area and to suggest the nature and probable causes of this particular type of wind erosion.

DESCRIPTION OF SOILS

The soils occurring on the area are characterized by a light brown to brown, sandy surface soil and a reddish brown sandy loam to sandy clay subsoil. In structure the surface soils are single grained and the subsoils are massive with a slight tendency to form columns. Of particular importance is the property of these subsoils to become very compact when dry. When they are exposed by erosion, they form an extremely hard, smooth surface. These soils are of a medium depth to deep, varying in the depth to calcareous material from about 2 to 5 feet. Small areas with lime at or near the surface are common. The areas, if large enough, are mapped as a shallow phase or as another series. Another variation is the occurrence of buried lake beds. These old lake beds are generally 2 feet or more below the surface and consist of a very dark, heavy, plastic clay. Such areas are for the most part quite small and are not delineated in ordinary Soil Conservation Service surveys, but are of importance in the present detailed study.

Two soil types, a fine sandy loam and a loamy fine sand, were mapped on 55% of the area.[5] The remainder of the area, due to severe

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Amarillo, Texas. Received for publication February 6, 1940.

[2]Junior Soil Technologist and Senior Soil Conservationist, respectively.

[3]WHITFIELD, CHARLES J. Sand dunes of recent origin in the southern Great Plains. Jour. Agr. Res., 56:907. 1938.

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[4]Original survey by Dave R. Cawlfield and Claude L. Fly, Soil Conservation Service.

[5]The two soil types would probably be correlated as Dalhart fine sandy loam and Springer loamy fine sand. These two series are differentiated entirely on subsoil texture. The Dalhart series has a sandy clay loam to sandy clay subsoil and the Springer series has a sandy loam to a sandy clay loam subsoil.

wind erosion with a subsequent loss of all of the topsoil, was mapped as eight subsoil types and dune sand. The subsoils have been grouped as follows:

1. Old lake beds consisting of a heavy, plastic, bluish-grey clay. After these lake beds have been exposed, very little additional erosion seems to occur, as evidenced by the fact that in some instances these areas are considerably higher than the surrounding subsoils. Three per cent of the area was mapped as this subsoil type.
2. Subsoil types with an estimated removal of from 8 to 15 inches. The surface of these subsoils is extremely hard and fairly smooth. Present surface texture varies from a sandy clay loam to a light clay. Erosion probably continues to remove some of the surface but at a much slower rate. These subsoil types were mapped on 17% of the area.
3. These subsoils are similar to those just mentioned except that they are much more severely eroded, having lost an estimated 2 to 5 feet of soil. This increased and variable erosion may be due to the fact that the original soils were lighter in texture and contained shallow areas. The surface is somewhat less compact than on the above group and varies in texture from a sandy loam to a sandy clay loam. These subsoils are generally calcareous. This group was mapped on about 8% of the area.
4. This subsoil presents an extremely severe case of wind erosion, the entire soil profile having been removed, leaving material consisting principally of soft caliche. Less than 1% of the area was occupied by this subsoil type.

Areas with a covering of sand varying from 2 to 3 feet up to 26 feet in the case of the largest dune were mapped as dune sand. This material consists of a rather heterogeneous mixture varying in texture from a loamy fine sand to a sand. It exhibits slight compaction in places but is for the most part extremely loose and friable. This dune sand was mapped on 16% of the total area.

Thus we find that about 45% of the area not only produces no vegetation, but presents an extreme hazard to the surrounding areas. This lack of vegetation is due to constant shifting of the sands on the dunes and to the hard smooth surface of the subsoils which present a clean sweep for the cutting action of the sand laden winds.

TYPE OF WIND EROSION

The type of wind erosion and dune formation with which we are here concerned should not be confused with dune formation occurring on sands. The latter is not of recent origin and occurs on deep, loose sands, derived in most cases from aeolian deposits. Furthermore, these dunes are fairly well stabilized by native vegetation. The dunes formed on the soil series already described, as well as on other series of a similar character, are of recent origin. They owe their formation to conditions of drought and over grazing. On the Dalhart Sand Dune Area, the origin is believed to be an 80-acre field. This field was cultivated from 1907 to 1914 and was then used for grazing. Prior to the

present studies, the experiment area had never been under cultivation except for this 80 acres.

An examination of the original survey indicates the presence of four rather distinct erosion types, *viz.*, (1) slight removal and shallow accumulations, (2) slight to moderate removal and moderate to severe accumulations, (3) severe to very severe removals and little or no accumulations, and (4) the sand dunes (Fig. 1).

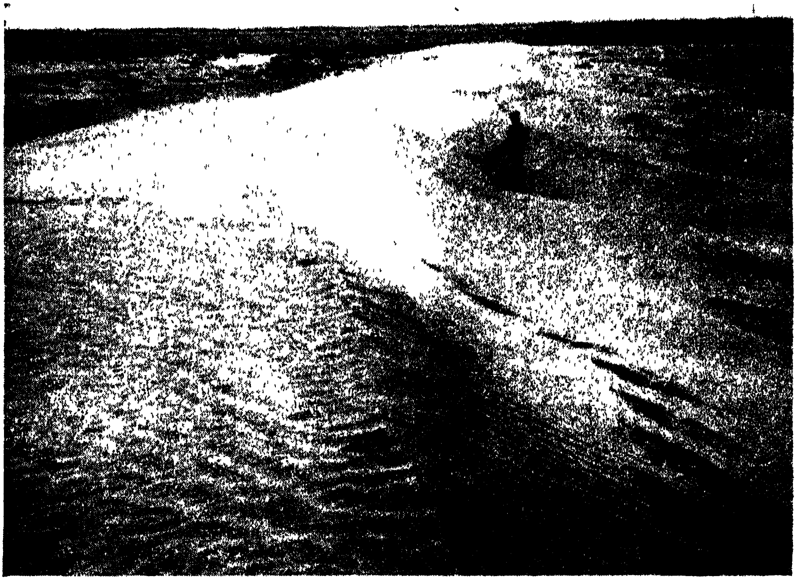

FIG. 1.—A view of sand dunes on the Dalhart Substation. In the background is the original vegetation; in midground slight to moderate removal and accumulations; and in the foreground are sand dunes.

These areas form a more or less definite pattern, starting with erosion type 2 and proceeding in a northeasterly direction in the order 2, 3, and 4. Type 1 which, comparatively, has not been greatly affected by erosion lies to the south and east of the other erosion types. There is, of course, some overlapping of these types. This is particularly true in the case of 3 and 4. The severely eroded and bare areas extend between the dunes. This arrangement of these erosion types probably is due to the direction of the prevailing winds which are from the south and southwest.

Reconstructing the probable sequence of erosion, we have first the original source which in this case was an old plowed field. Top-soil from this source moves in a northeast direction and is caught on adjoining areas in small hummocks or is fairly well distributed over the area. At any rate, enough sandy material moves in to give a decrease in vegetation on the new area, thus producing still more erosive material. The hummocks form still larger hummocks which finally coalesce, forming small dunes. These dunes continue to grow in size

as they move forward until large severely eroded areas are left in their wake. As these dunes continue to grow in size, their movement

FIG. 2.—The smooth subsoil surfaces between the dunes were listed to promote vegetative growth.

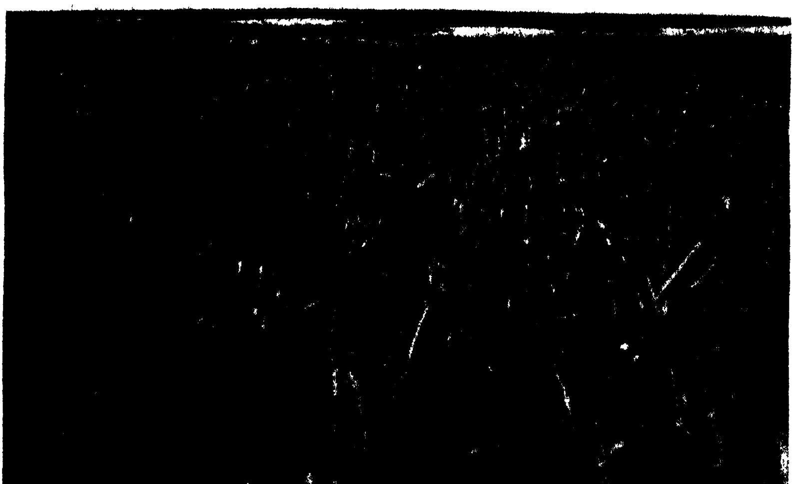

FIG. 3.—Vegetation, planted around the dunes, catches and holds drifting sand; remaining sand areas finally level out in the established cover crops.

becomes very much slower. However, some of the dune material is carried beyond the dunes, forming a new area of rather severe accumulations so that the process of dune formation is again repeated.

CHANGES DUE TO TREATMENT

All of the various methods to reduce the size of the dunes, as the first step in stabilization, depend primarily on wind action. The smooth subsoil surfaces between the dunes are listed both to form a rough surface to hold the sand and to promote vegetative growth which will catch and hold still more sand (Figs. 2 and 3). It should be kept in mind that the lack of vegetation is not due to any lack of productive capacity in either the subsoils or the dune sand. However, the spreading of sandy material over exposed subsoils and the sub-

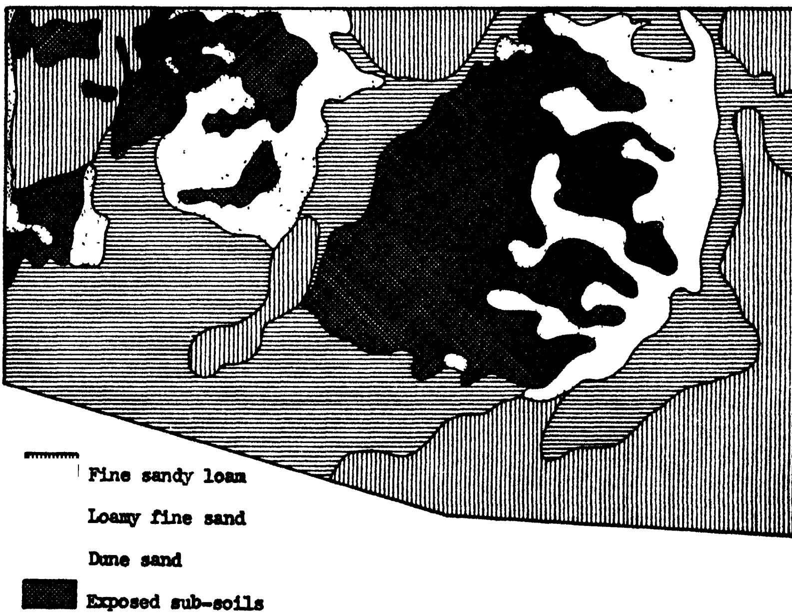

FIG. 4.—Soil types and severely eroded areas in April, 1936, on the Dalhart Sand Dune Area. Scale, 4 inches = 1 mile.

sequent mixing of these materials by cultivation tends greatly to improve these soils from a purely physical standpoint. The resulting soil not only has a fairly high water-holding capacity but a high rate of absorption as well. The only exceptions are subsoil type 1 (old lake beds) which will support little vegetation due to its droughty condition and subsoil type 7 (raw caliche). These two types occupy about 3% of the area. They require a covering of sandy material before much vegetative growth can be induced.

The important changes in soils that have occurred may be noted by a comparison of the two maps (Figs. 4 and 5). The changes in both soils and erosion are summarized in Table 1. Dunes more than 6 feet in height, originally occupying an area of 45 acres or 5% of the total area, were reduced to one small dune of about ½ acre which was just over 6 feet in height. The area occupied by dunes from 3 to 6 feet in height was subsequently increased from 13 acres to 23 acres.

However, these smaller dunes have lost most of their dune characteristics in size, shape, and compaction, and have become partially or completely stabilized. The area originally mapped as exposed subsoils was reduced from about 260 acres, or 28% of the total area, to 45 acres. This remaining subsoil area is confined principally to a portion of the area on which no treatment was applied other than the accumulation of sand from the surrounding treated areas. This accumulation has brought about vegetative growth so that less than 1% of the total area now consists of "bare" subsoils. An increase in accumulations in the less eroded areas was observed. This occurred principally in that portion of the area adjacent to the dunes. These accumulations are in the form of hummocks and cover less than one-third of the area involved.

TABLE 1.—*Changes in soils and wind erosion on the Dalhart sand dune area.*

Soils	Apr. 1936, %	Aug. 1939, %
Loamy fine sand	24	32
Fine sandy loam	31	38
Loamy fine sand (shallow phase)	—	6
Dune sand	17	18
Subsoil No. 1	3	3
Subsoil No. 2	18	1
Subsoil No. 3	7	2
Subsoil No. 4	—*	—*
Wind erosion:		
Accumulations:		
6–12 in	4	—
12–36 in	13	—
36–72 in	1	6
72 in. and above	5	—*
Removals:		
A horizon and portion of B horizon	18	—*
Lower B horizon and portion of C horizon	5	—*
Removals and accumulations:		
Removal less than 25% of A horizon; accumulations less than 6 in	17	1
Removal less than 25% of A horizon; accumulation 6–12 in	4	—
Removal, 25–75% of A horizon; accumulation less than 6 in	4	7
Removal, 25–75% of A horizon; accumulation 6–12 in	20	25
Removal, 25–75% of A horizon; accumulation 12–36 in	4	34
Removal, A horizon and portion of B horizon; accumulation less than 6 in	—	8
Removal, A horizon and portion of B horizon; accumulation 12–36 in	1	12
Removal, lower B horizon and portion of C horizon; accumulation less than 6 in	—	3
Removal, lower B horizon and portion of C horizon; accumulation 6–12 in	4	—
Removal, lower B horizon and portion of C horizon; accumulation 12–36 in	1	2

*Less than 1%.

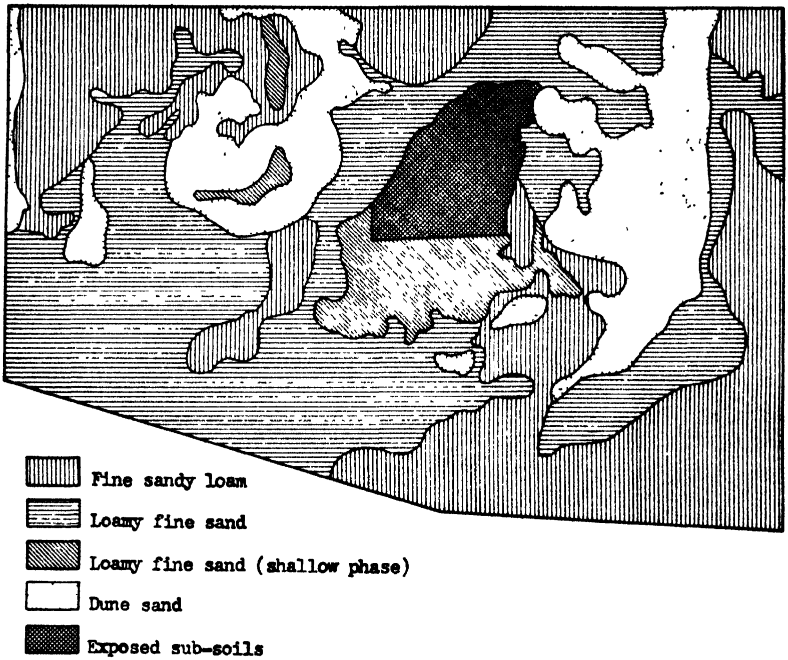

FIG. 5.—Soil types and severely eroded areas in August, 1939, on the Dalhart Sand Dune Area. Scale 4 inches = 1 mile.

It is rather difficult to say just when enough erosion changes have taken place to produce another soil type. However, the following differences were noted in a comparison of the two surveys: The fine sandy loam was increased from 24% to 32%. This change, as has already been noted, was due to the deposition of soil material on exposed subsoil and the subsequent distribution and mixing with the subsoil. The loamy fine sand was increased from 31% to 38% for the same reason as given above. The subsoils suffering from extreme erosion were mapped as fine sandy loam (shallow phase), less than 1%, and loamy fine sand (shallow phase), 6%. No change was noted in the amount of subsoil types 1 and 4. Some shifting of the dune sand occurred although the total acreage remained about the same.

SUMMARY

The changes that have occurred over a period of 3½ years in soils and erosion on a severely wind-eroded area have been presented. It is rather difficult to express these changes quantitatively. However, an attempt has been made to show that, although these medium textured to sandy soils have suffered from extreme wind erosion, the treatment applied has sufficiently modified their physical condition so that their productive capacity very nearly equals the productive capacity prior to accelerated wind erosion.

BORON DEFICIENCIES AS REVEALED BY PLANT AND SOIL TESTS[1]

K. C. BERGER AND E. TRUOG[2]

WHEN boron becomes deficient certain external and internal changes occur in plants, such as heart and dry rot of sugar beets, black spot of garden beets, brown heart of turnips, cracked stem of celery, corky core of apples, and yellowing of alfalfa. However, before these symptoms show up in the plants, a reduction in yield usually takes place. Since certain plants, such as the legumes and many truck crops, require more boron than other plants, notably the grasses, they can be used to better advantage as indicator plants.

The amounts of boron found in plant tissue give some indication of the amounts of available boron in the soils on which the plants were grown. Results presented by the authors in a previous paper[3] show that alfalfa plants provided with a plentiful supply of available boron contained from 30 to 50 p.p.m. of boron in the dry tissue, while those provided with an insufficient supply for normal growth contained only 8 p.p.m. Similarly, when beets were grown on a soil low in available boron, they contained only 14.5 p.p.m. of boron, while the beets grown on this same soil which had been fertilized with boron contained 24 p.p.m.

METHODS AND MATERIALS

The quinalizarin color reaction described by the authors[4] was used in all the boron determinations. The available boron of soils was extracted by refluxing 20 grams of soil with 40 cc of water for 5 minutes. An aliquot of the filtered extract was then made alkaline and evaporated to dryness. The residue was ignited to destroy organic matter and nitrates and then taken up with dilute acid, after which the quinalizarin colorimetric test for boron was applied.

In the determination of total boron in soils a sodium carbonate fusion was made and the resulting melt was dissolved at pH 5.5 to 6.0 with sulfuric acid. The resulting solution was made up to 500 cc with alcohol, centrifuged, and an aliquot made alkaline and evaporated to dryness. After ignition and dissolving in dilute acid, the quinalizarin test was applied.

In the determination of total boron in plants, the plant tissue was ignited to a gray ash, which was taken up with dilute acid. The quinalizarin test was then applied to some of the clarified extract.

The beets which were analyzed were grown on experimental plats, the soil of which is a Poygan silty clay loam.[5] The surface soil to a depth of 6 inches consists

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Presented before the Division of Fertilizer Chemistry at the ninety-eighth meeting of the American Chemical Society in Boston, Mass., September 11–15, 1939. This work was supported in part by a fellowship grant from the American Potash Institute, Inc. Received for publication February 6, 1940.

[2]Fellow and Professor of Soils, respectively.

[3]BERGER, K. C., and TRUOG, E. Ind. Eng. Chem., Anal. Ed., 11:540. 1939.

[4]*Loc. cit.*

[5]The authors are indebted to Dr. J. C. Walker and his associates for making available from these plats the samples of soil and figures relative to the incidence of black spot.

of black friable silty clay loam with some fine sand. The subsoil consists of a dull-red clay which is calcareous. Part of the field on which the plats were laid out had been limed previously and the reaction of the plats varies from pH 6.0 to 8.0 The plats all received a basic treatment of phosphate, nitrogen, and potash, and in addition they received various amounts of borax ranging from 0 to 60 pounds per acre. All treatments were quadruplicated.

PLANT TESTS

Fig. 1 gives results showing the relationship of the amounts of boron found in red beet leaves to the amounts of available boron found in the soil on which these beets were grown. There appears to

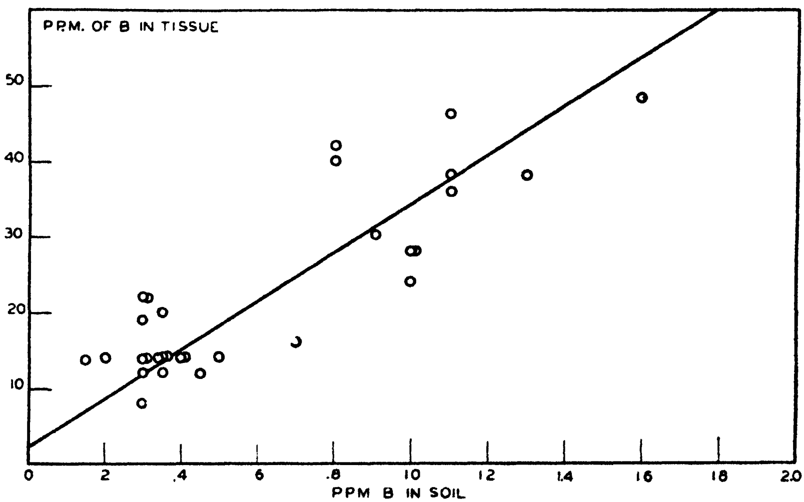

FIG. 1.—Relationship of available boron in soils to total boron in plant tissue of red beet leaves.

be a good correlation between the amounts of available boron found in the soil and the amounts of boron found in the dried beet leaves. Analysis of plant tissue thus offers some promise as a method of determining the level of available boron in soils.

SOIL TESTS

The boron present in soils may be divided into three categories, namely, total boron, acid-soluble boron, and water-soluble boron. The total boron content of a soil is not a good indicator of the adequacy or need of boron fertilization, because generally, less than 5% of the total boron in soils is in an available form. The unavailable portion is often present largely as tourmaline. Experimental tests indicate that tourmaline is not very available to plants. Fig. 2 shows sunflower plants which were grown in nutrient solutions similar in all respects with the exception of the boron content. Culture A received no boron other than that found in the seed and as impurities in the chemicals. The plants are small and growth has ceased. Culture B

received 0.5 gram of 100-mesh tourmaline. A small amount of growth was made over that produced in culture A, but the terminal bud is dead. Culture C is a normal sunflower plant which received 1.0 p.p.m. of boron in the form of boric acid in the nutrient solution.

The amount of acid-soluble boron found in soils may be larger or smaller than the amount of boron extracted with boiling water. It was found that the concentration of acid used, the method of agitation during extraction, and the temperature at which the extraction is conducted affect the final result.

Table 1 gives the amounts of boron extracted by various solvents from the soil taken from a number of the experimental plats and

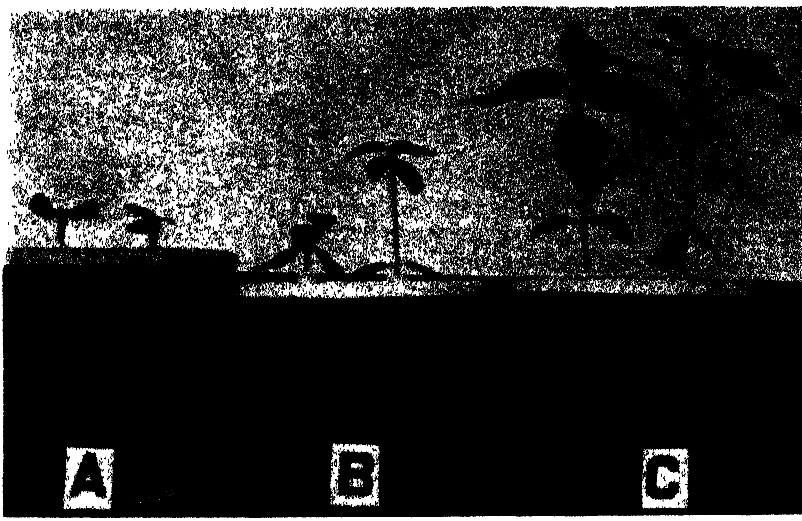

FIG. 2.—Sunflowers grown in water cultures. A, no boron added; B, 0.5 gram of 100-mesh tourmaline added; and C, 1.0 p.p.m. B as boric acid added.

also the percentages of black spot present in the beets grown on these plats. There apparently is little correlation between the amounts of total boron found in the soils and either the amounts of water-soluble boron or acid-soluble boron. Neither is there a good correlation between the amounts of acid-soluble boron and the percentages of black spot which occurred.

Difficulties are encountered in acid extractions with soils containing large amounts of free calcium carbonate, because such soils may completely neutralize a dilute acid used in the extraction. Furthermore, if a stronger acid is used, the resulting extract will contain such a large amount of salt that a laborious and time-consuming process is encountered in separating the salt before the boron can be determined.

The amount of boron extracted from a soil by boiling 20 grams of soil with 40 cc of water for a period of 5 minutes appears to correlate fairly well with crop responses to boron fertilization. In Fig. 3 the amounts of boron extracted by this method are plotted against the indexes of black spot in red beets. The index of discoloration is a

TABLE 1.—*Amounts of boron extracted from soils with various procedures.*

Plat No.	Borax applied per acre, pounds	pH	Equivalent $CaCO_3$ present, %	Beets affected with black spot, %	Amounts of boron found				
					Water extraction p.p.m.*	Acid extraction p.p.m.†	Acid extraction p.p.m.‡	Acid extraction p.p.m.§ tion	Total p.p.m.‖
II-10	0	8.0	9.5	98	0.3	0.2	0.9	0.2	13
II-9	20	8.0	9.5	35	0.6	0.3	0.45	0.3	14
I-1	20	6.0	0.0	5	1.5	0.7	2.2	1.3	17
II-2	20	6.2	0.0	11	1.6	0.8	2.7	1.8	10
II-7	40	8.0	2.5	39	0.5	0.8	1.9	1.0	12
II-1	40	6.0	0.0	13	1.8	0.8	2.5	1.6	11
III-1	40	6.2	0.0	16	1.1	0.8	2.3	1.9	15
II-4	60	7.8	1.5	2	2.0	1.4	5.2	4.2	11

*The water extraction was made in accordance with the method of extraction of available boron previously described in this paper

†Acid extraction involved treatment of 20 grams of soil with sufficient sulfuric acid to neutralize carbonates present and to give an excess of 1.0 cc of 1.0 normal sulfuric acid in all cases. The volume of acid was adjusted to 40 cc with distilled water and the samples were shaken for a period of 30 minutes.

‡Acid treatment involved the same proportions of soil, acid, and water but the samples were boiled for 5 minutes, under a reflux condenser, instead of shaken for 30 minutes.

§Acid treatment consisted of shaking 20 grams of soil and 40 cc of 0.1 normal sulfuric acid for a period of 30 minutes.

‖The determination of total boron in the soil was made in accordance with the method previously described in this paper.

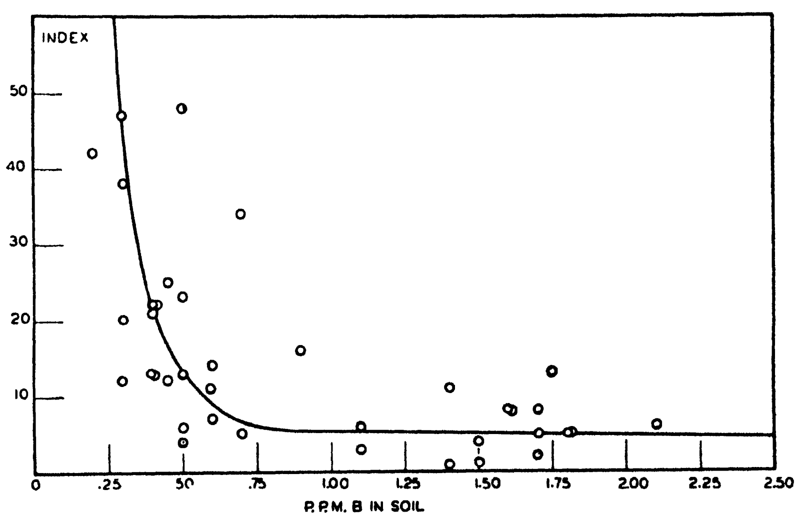

FIG. 3.—Comparison of amounts of available boron in soils to black spot index in beets.

combination of the percentage of beets affected with black spot and the severity of the blackening. Walker and his associates[6] describe the method of determining the index and state that an index of 0

[6]WALKER, J. C., JOLIVETTE, J. P., and McLEAN, J. G. Canning Age, 19:489. 1938.

indicates that there is no blackening whatsoever, while an index of 100 indicates that all of the beets are severely blackened. The index appears to give a somewhat better indication of the degree of the boron deficiency than does the percentage of beets affected with black spot alone. Considering the numerous factors involved, the correlation between the percentages of black spot found in the beets and the amounts of water-soluble boron found in the soils appears to be fairly satisfactory.

SUMMARY

The amount of boron present in the leaves of table beets gives an indication of the amount of available boron present in the soils on which the beets were grown. Thus, plant tissue analysis for boron may be used to determine the level of available boron in soils.

The boron present in soils may be divided into three categories, namely, total boron, acid-soluble boron, and water-soluble boron. Results of analyses show that the total boron content of a soil is not a reliable indicator of the need for boron fertilization because, generally, less than 5% of the total boron is in available form. The unavailable, or better, difficultly available, form is often present largely as tourmaline. The acid-soluble boron content of a soil gives a somewhat better indication, but does not appear to correlate as well with the incidence of black spot in garden beets as does the amount of boron extracted with boiling water. Furthermore, acid extractions introduce difficulties in the case of calcareous soils, since these may neutralize all or a part of the acid. Extraction by treatment of the soil with boiling water for 5 minutes appears, at the present, to be the best method of extracting what may be called the available boron in soils.

LEAF PIGMENT CONCENTRATION AND ITS RELATION TO YIELD IN FAIRWAY CRESTED WHEAT GRASS AND PARKLAND BROME GRASS[1]

I. J. JOHNSON AND ELMER S. MILLER[2]

AMONG the various plant pigments found in green leaf tissues, chlorophyll has been the subject of extensive investigation in greenhouse and laboratory researches. Field experiments on the relation between chlorophyll concentration to yielding ability in corn have been reported by Sprague and Curtis (7)[3] and by Miller and Johnson (4). In the previous study (4), there was no significant correlation of chlorophyll concentration or carotenoid concentration and yield among inbred lines and single crosses in field and sweet corn.

The carotenoid pigments in forage crops are of special interest because certain ones possess vitamin A activity. Among the yellow pigments found in plant material (6), only alpha, beta, and gamma carotene and cryptoxanthin possess vitamin A activity. In green leaf tissue, beta carotene is the principal source of vitamin A, one molecule being equivalent to two possible molecules of vitamin A. Leaf xanthophyll and zeaxanthin, the dominant yellow pigments in green leaf tissue, possess only a slight, if any, vitamin A activity.

The present study was made with forage grasses to determine the extent to which chlorophyll and carotenoid pigment concentrations varied among clonal lines and to determine the possibilities of breeding strains of superior nutritive value. Additional information on the relation between chlorophyll concentration and yield seemed desirable.

MATERIAL AND METHODS

The material analyzed for pigment concentration and yield consisted of a group of 55 clonal lines of Fairway crested wheat grass and 76 of Parkland brome grass. These lines came from individual plants selected in 1937, subdivided, and transplanted in duplicate 4.5 foot rows at University Farm, St. Paul, and at the Waseca branch station.

Leaf samples from fully headed plants were collected in each of the duplicate plots grown at University Farm. All plots were sampled on the same day. Each sample for pigment analysis consisted of seven to eight leaves, selecting the third leaf from the top to overcome a possible variability due to positional effect on the plant. Three samples were taken from each row, placed in a glass vial, stoppered, and immediately frozen in the field with dry ice. The frozen samples were then

[1]Contribution from the Divisions of Agronomy and Plant Genetics and Botany, University of Minnesota, St. Paul, Minn. Paper No. 1782 of the Journal Series, Minnesota Agricultural Experiment Station. Aided by a grant from the Graduate School of the University of Minnesota. Assistance in the preparation of these materials was furnished by the personnel of Works Project Administration Official Project No. 65-1-71-140, Subproject No. 331, and Project No. 665-71-3-69, Subproject No. 409. Received for publication February 19, 1940.

[2]Professor and Research Professor of Farm Crops, Iowa State College, Ames, Iowa, Formerly Associate Professor of Agronomy and Plant Genetics, University of Minnesota, and Assistant Professor of Botany, University of Minnesota, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 306.

stored 4 months at $-15°$ C before they were studied. Of the three samples, one was used for analysis, one for dry matter determination, and the third preserved for use as a re-check if needed. The sample for analysis (0.5 to 1.0 gram) was weighed, moistened with acetone, ground with washed sand in a mortar, and the pigments extracted immediately with acetone for 1 hour in a Goldfisch extractor. The acetone solution of pigments was then transferred to an ether solution in a separatory funnel. The concentration of chlorophyll, total carotenoids, and Beta carotene were determined spectrophotometrically according to the method described by Miller (3). All reported results on pigment analysis are based on a dry weight basis.

The yield of the clonal lines in tons per acre on a green weight basis are based on the average of the two replicates grown at University Farm.

EXPERIMENTAL RESULTS

VARIABILITY IN PIGMENT CONCENTRATION AND YIELD

From the analyses of variance of the results obtained in the study of pigment concentration and of yield in duplicate plots, a frequency distribution of the clonal lines was made to show the extent of their variability from the mean of their population. The classes used were made on the basis of the standard error of a difference ranging from five times the standard error of the difference above and below the mean. The distribution of the strains of Fairway crested wheat grass and Parkland brome grass in Table 1 shows a wide range in variability for the pigments studied.

In Fairway crested wheat grass the strains varied in percentage of total carotenoids from four times the standard error of the difference below the mean to five times the standard error of the difference above the mean. The strains ranged from 13.1×10^{-4} to $32.0 \times 10^{-4}\%$ total carotenoids on a dry weight basis.

In beta carotene concentration, the strains varied from five times the standard error of a difference below the mean to five times the standard error of a difference above the mean and ranged from 3.8×10^{-4} to $10.5 \times 10^{-4}\%$ on a dry basis. For total chlorophyll, the range in distribution of strains was likewise very large. Although the strains varied significantly in yield, the distribution varied only from two times the standard error of a difference below to three times the standard error of a difference above the mean. More than one-half of the strains did not yield significantly different from the mean. The rather high standard error of the mean (approximately 10%) probably was due to the small plot size. The strains ranged in yield from 3.72 to 8.21 tons per acre on a green basis.

The distribution of the 76 clonal lines of Parkland brome grass also shown in Table 1 indicates wide differences in pigment concentration and a somewhat similar distribution for yield as in the case of Parkland brome grass. Because of a larger standard error, the range in distribution of lines analyzed for pigments was not as great as for Fairway crested wheat grass. The larger pigment analysis error may have been due to lodging among the clonal lines, making the selection of uniform analysis samples in the field more difficult. The range in

TABLE 1.—*Frequency distribution of clonal lines of Fairway crested wheat grass and Parkland brome grass analyzed for percentage total chlorophyll, total carotenoid pigments, Beta carotene, and yield in tons per acre compared with the means for their respective populations.*

Characters studied	No. of lines below mean, Standard error of difference times					No. equal	No. of lines above mean, Standard error of difference times					Mean	Standard error	Range
	5+	4	3	2	1		1	2	3	4	5+			
Fairway Crested Wheat Grass														
% total carotenoids	0	2	10	9	4	9	2	6	8	0	5	20.0×10^{-4}	1.05	13.1–32.0
% beta carotene	3	5	4	8	3	11	6	1	3	4	7	6.3×10^{-4}	0.33	3.8–10.5
% total chlorophyll	0	3	5	5	8	16	8	4	2	2	2	1.30×10^{-2}	0.05	0.93–1.88
Tons per acre (green)	0	0	0	4	12	30	5	2	2	0	0	5.69	0.53	3.72–8.21
Parkland Brome Grass														
% total carotenoids	0	0	4	10	16	23	8	13	1	1	0	18.8×10^{-4}	1.64	10.2–30.3
% beta carotene	0	0	0	11	16	24	8	8	4	3	2	6.2×10^{-4}	0.65	3.4–12.4
% total chlorophyll	1	1	3	5	11	38	13	2	1	0	1	1.38×10^{-2}	0.13	0.54–2.11
Tons per acre (green)	0	0	0	2	12	52	5	4	1	0	0	7.73	0.79	5.26–12.02

pigment concentration among the strains of *Bromus*, however, was as great or greater than for Fairway crested wheat grass, varying from 10.2×10^{-4} to 30.3×10^{-4}% of total carotenoids; 3.4×10^{-4} to 12.4×10^{-4}% of beta carotene; and 0.54×10^{-2} to 2.11×10^{-2}% of total chlorophyll, while the range in yield was from 5.26 to 12.02 tons per acre.

CORRELATION BETWEEN PIGMENTS AND BETWEEN PIGMENT CONCENTRATION AND YIELD

Since previous results reported on the relation between pigment concentration and yield were made with ear corn, it seemed desirable to extend these studies to include forage grasses where the yield of the entire plant was included. The correlation coefficients given in Table 2 between yield in green tons per acre and concentration of total chlorophyll and beta carotene show essentially the same relationship as found with corn and indicate that pigment concentration appears to have no real relationship to yielding ability in either of the two grasses. The significant positive correlation between total chlorophyll and either total carotenoids or beta carotene is in agreement with results previously published (4) from analysis of corn leaf tissue. On the basis of these results, the selection of darker green strains of grasses should be a fair criterion for selecting superior strains in respect to carotenoid pigments.

TABLE 2.—*Relation between total chlorophyll, total carotenoids, and beta carotene concentration to yield per acre and between chlorophyll and carotenoid pigment concentration in crested wheat grass and Parkland brome grass.*

Characters correlated	Crested wheat	Parkland brome
% total chlorophyll and yield in tons per acre	−0.0189	0.0057
% total chlorophyll and % total carotenoids	0.5655	0.6339
% total chlorophyll and % beta carotene	0.4289	0.5481
% beta carotene and yield in tons per acre	0.1428	−0.0417
Level of significance, 5% point	0.2732	0.2319

DISCUSSION

From the data presented in Tables 1 and 2 it is evident that a wide range in variability in pigment concentration may be found among individual plants in commercial strains of the two grasses studied. The importance of this variability from a plant selection standpoint in forage improvement is of particular significance in its relation to vitamin A. The improvement of grasses in nutritive value should be an important phase of any forage improvement program.

The consistent lack of significant relationship between chlorophyll concentration and yield in all studies conducted at Minnesota would indicate that under natural field conditions the amount of chlorophyll present in leaf tissue is more than adequate for normal photosynthetic processes and that among strains of crop plants other factors, genetic or physiological, are of greater importance in modifying yielding

ability. The high correlation between total chlorophyll and carotenoid pigments has been consistent in all previous work. At present, no explanation can be offered for these findings save that apparently in an indirect manner the yellow pigments are effective in or by photosynthesis.

In the methods of sampling and analysis employed in this study certain sources of error have been encountered. As previously stated, the dry matter determinations were not made on the sample analyzed but on an equivalent sample. In the majority of cases, the differences in amount of dry matter between duplicate plots were less than 2%, but in some instances the differences were as great as 7%. These differences may have been due to a tendency for ice crystals to form on the sides of the glass vial during storage. The dry matter percentage applied to the sample analyzed may not have been strictly correct. Since the variability between strains was very large, this factor probably did not modify greatly the final results.

Previous studies by Miller and Johnson (4) suggested that enzymatic reactions during storage at -15° C were insignificant in influencing the plant pigment concentration. Recent investigations by McKinney (2) and Barnes, *et al.* (1) suggest the advisability of inactivation of enzymes by heat before the samples are stored.

In this study the authors have favored the methods consistently giving the highest values, especially in the extraction, fractionation, and analyses of beta carotene. For a detailed review of the possible sources of error in studies of this type, the reader should consult Strain (8) and Miller (5).

SUMMARY

In a study of 55 clonal lines of Fairway crested wheat grass and 76 clonal lines of Parkland brome grass, widely significant differences were obtained in percentage of total carotenoid pigments, beta carotene, and total chlorophyll. The strains studied varied significantly in yield on a green weight basis.

No significant relationship was found between the concentation of chlorophyll or carotenoid pigments and yielding ability.

Significant correlations were obtained between the concentration of total chlorophyll and either total carotenoids or beta carotene.

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THE USE OF MODERN STATISTICAL METHODS IN FIELD EXPERIMENTS[1]

S. C. SALMON[2]

IN considering statistical methods for interpreting the results of field experiments, all, no doubt, will agree that in order to be useful, these methods must not only be sound in themselves but also that they be soundly applied; specifically that the assumptions on which they are based be valid. It seems clear that in many cases the assumptions underlying such usage in the past were not valid, and furthermore, that some of those underlying a similar use at the present time are at least questionable. The primary purpose of the present paper is to indicate the need for critical consideration of the assumptions involved whenever modern statistical methods are used in interpreting the results of field experiments.

The subject matter of this paper can be epitomized by a statement a former teacher of biometry often repeated to his classes. The statement was about as follows: "The statistical method is nothing but common sense expressed in the most beautiful language." There was at least one member of the class who did not understand the language very well. Others were more impressed and intrigued by its beauty and its elegance than with the thoughts it was intended to convey, and probably many failed to realize a very important implication, namely, that if the statistical method is nothing but common sense expressed in a different language, then deductions based on statistical interpretations and those based on common sense ought to agree. Furthermore, if they do not agree, something is wrong with either the statistics or the common sense.

It should not be inferred that when there is disagreement the statistical method or its application is always at fault. Such is believed often to be the case and that viewpoint will be stressed not because it is the only one worthy of emphasis but because it has received, it seems, too little attention. It should be noted, however, in passing, that common sense in itself is not a sufficiently reliable guide to what is true and correct. Too often it serves only as a cloak or a blind for ignorance, prejudice, and preconceived opinions. In fact, one of the greatest advantages that may be claimed for the statistical method is that it aids in arriving at truly objective interpretations. Perhaps it is sufficient for the present to be reminded that it was prejudice supported by common sense that would have sent Galileo to the stake had he not recanted, led Lavoisier to the guillotine in the French Revolution, would have stopped Pasteur's work with anthrax and rabies, and would have sent Harvey to an insane asylum had it prevailed.

Moreover, let no one assume it is only the ignorant and the uninformed who are swayed by prejudice. Probably no one so frequently

[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, also presented as part of a symposium on "The Use of Statistical Methods" at the annual meeting of the Society in New Orleans, La., November 22, 1939. Received for publication February 23, 1940.

[2]Principal Agronomist.

and contemptuously ridiculed Pasteur as did Liebig, and certainly no one opposed him so strenuously as did the physicians of Paris. But this is no occasion for a discussion of the limitations of common sense. What should be emphasized is that we should be most careful that our adherence to common sense does not prejudice our opinions and discourage the use of any tool, statistical or otherwise, that may be found useful in interpreting experimental results.

Perhaps the need for care in applying statistical methods can be emphasized best by presenting a bit of history relating to their use in interpreting field experiments, cite a few examples, and suggest some of the precautions that should be observed.

The use of modern statistical methods for field experiments in this country began soon after the publication of Wood and Stratton's (8)[3] paper in 1910 in which they discussed some of the fundamentals of the probable error (or standard error) concept and showed how it could be used in the interpretation of experimental data. One important result of this paper, and others which followed soon after, was the substitution of replicated experiments for single plot experiments which previously had generally been used, especially for variety and similar tests. The duplication or replication of plots was not then a new idea, and in fact had occasionally been used by agronomists at least 20 or 25 years previous to that time. What this concept did perhaps more than anything else was to rationalize the principle of plot replication, and impress upon agronomists the need for consideration of random errors in field experiments. These early papers also accomplished an important result in putting a tool into the hands of the agronomist by which he could measure the random variation in experimental fields and compare more precisely the suitability of different fields for experimental work; also by means of which he could more accurately evaluate the results of experiments repeated a large number of times as, for example, cooperative experiments with farmers.

This tool also has been useful in comparing the effect on variability of different methods of preparing the ground, sequence of crops, methods of decreasing variability by uniform cropping, leveling land, etc., preliminary to the laying out of experiments. Statistical tools have been of great value in reducing and summarizing large volumes of data so they may be visualized by the investigator. They have been equally important in condensing and summarizing data for publication. While it is difficult to cite any figures to show the net result of using statistical methods in these various ways, it can hardly be doubted that in the aggregate they have been very important.

It was soon after the appearance of Wood and Stratton's paper that we first began using probable errors and standard errors to evaluate experiments; and it was then it seems that our troubles began. One of the first attempts made use of the abbreviated formula for the standard error of a difference, which states that it is equal to the square root of the sum of the squares of the respective standard errors. It was not until nearly 15 years later that agronomists learned that this formula is incorrect for many field data since it assumes no

[3]Figures in parenthesis refer to "Literature Cited", p. 319.

correlation between the variables being compared, whereas obviously in many cases the correlation is very important. The difficulty, of course, lay in the use of the abbreviated instead of the complete formula, including the correlation term.

It was about this time, also, that it was realized that errors calculated from two or three plots did not mean very much, and consequently the practice developed of pooling data in order to obtain a more accurate estimate of error. This method, of course, is still used, and within limits and with suitable precautions is a perfectly valid and useful procedure. It was assumed, however, that it was necessary to express errors as a percentage of the mean before they could be pooled, an assumption which, as we now know, was decidedly wrong in most cases though not always so. But strangely enough, when analysis of variance entered the picture, some 15 years ago, a directly contrary assumption was made, namely, that errors are independent of the mean values being determined, and it was not until Cochran's (1) paper appeared last year that it was generally admitted and became widely known that such frequently is not the case.

The coefficient of variability has not only been used as indicated above, but has sometimes been referred to as "the best measure of variability"; when, as a matter of fact, it is nothing more nor less than a measure of relative variability and may be and often is a very poor measure of variability as such. It seems to have taken a long time to discover this fact, though it should have been obvious from the very nature of the coefficient of variability itself.

Another erroneous application of the statistical method, which fortunately has not been made very frequently but is nevertheless worthy of mention, is the use of the formula for the standard error of a grand average which is given as equal to $\frac{1}{N} \times$ the square root of the sum of the squared errors of the respective averages. This formula, of course, is perfectly valid when the individual averages and the errors of those averages belong to the same statistical population. The difficulty is that it has been used without any regard to this limitation.

Additional examples could be given, but it would seem more useful at this point to consider just why it is that these errors, misconceptions, or failure to consider limitations have arisen. The reason appears to be simple. On the one hand, few agronomists had had any training in statistics, or professed any knowledge of the fundamentals of the statistical method. They were, in fact, encouraged to believe that it was not necessary to have more than a superficial knowledge of statistics in order to use them satisfactorily. They were told frequently, and in no uncertain terms by what appeared to be the best of authority, that statistical methods were necessary; that unless these methods are used their experiments, to cite a few of the phrases from the literature of the past 15 or 20 years, are "inadequate, and as likely as not to lead to incorrect conclusions," not only "not worthy of serious consideration but may be a veritable detriment to practical agriculture and discreditable to agronomic science," that "they are of little significance," and that they are not "worth what they cost,"

etc. Naturally, agronomists were somewhat concerned. Some perhaps were a bit frightened. Most of us were impressed by the complicated formulae we did not understand, by the authority of mathematics, the most exact of the sciences, and perhaps most of all by the complacent assurance of the proponents of the new methods. These, like an opiate, dulled our critical sense and gave us a feeling of confidence which though spurious was very comforting, especially when as was often the case they supported conclusions we hoped were true or which had been arrived at by other means.

We were not aware that statistics is a complex subject, that various assumptions are involved in all statistical formulae, and that the soundness of any conclusions that are reached depend quite as much upon these assumptions as on the correctness of the formulae themselves. Furthermore, the various assumptions, if stated at all, were often in language ambiguous to the agronomist and seldom if ever emphasized.

No attempt will be made to discuss the matter from the statistician's point of view. However, it is no adverse criticism and a fact that he perhaps will be the first to admit that, generally speaking, few statisticians have been familiar with agronomic problems or agronomic technic. He is excusable if he did not know that agronomy also is a complex subject and that the inter-relations between plants, on the one hand, and the soil, climate, weather, the hundreds of diseases, including many races, weeds, insects, etc., on the other, are anything but simple.

Perhaps it never occurred to him that the formulae he so carefully checked in his study or laboratory involved assumptions not always realized in an experimental field. To cite a single example, it is not strange that both agronomists and statisticians have failed to note that chi-square for independence is not a satisfactory tool for determining whether differences in bunt infection of different selections of wheat are statistically significant though a most useful one for other problems that appear to be identical, such, for example, as differences in percentages of plants having red grain from a cross involving white-grained and red-grained parents. It is easily overlooked that in the former case one is dealing with heterogeneous populations and in the latter with homogeneous populations for the reason that bunt infection is greatly affected by variation in soil, whereas red grain color is affected very little if at all.

But most of us perhaps are more interested in the present and future than in the past. One might suppose in view of the very great interest in the subject, the voluminous literature, including several books, and the nearly 30 years' experience in using statistical methods, that the difficulties of the past are behind us and that we might confidently proceed with the use of currently recommended methods. Let us hope that this is the case, though it appears that such would be an optimistic appraisal of the situation.

Current recommendations seem to imply that the statistical method should be considered not merely as a tool to be used by the agronomist if and when occasion demands, but rather as a method of research complete in itself. A sort of super-science, if you please, that deter-

mines the design of experiments and directs the interpretation of experimental data. Indeed, so far as field experiments are concerned, instead of being told, as we once were, that statistical methods are indispensable, it now seems to be the common opinion that they are not applicable at all to most field experiments of the present day, because the latter are not properly laid out. What must be done is to set up entirely new experiments designed in the light of approved statistical methods, so that these latter may properly be applied and results secured that will be dependable beyond a possible shadow of doubt. Specifically, the plots must be arranged at random, and they must be replicated sufficiently so that unquestionably valid estimates of error may be derived. A recent writer in discussing varietal trials at several stations in a state over a period of years goes so far as to say "it is only when the number of stations and years can be considered an adequate sample of all possible places and years, that worth-while predictions can be made for all places in the state and for future years." Another implies that stations in a state as well as plots in a field must be selected at random if reliable conclusions are to be expected. Unfortunately, neither author tells us how such tests, numerous as they must be, are to be financed and managed. Nor do they tell us how many seasons or places are necessary for an adequate sample, nor how it has been possible for agronomists to have made any progress in the past considering that these methods have not been used.

It may safely be assumed that most agronomists would hope to be the last to discourage the use of any methods likely to lead to better and more efficient experimentation. On the contrary, they would prefer to be among the first to encourage such use.

There are, however, a number of circumstances that suggest a certain degree of caution before accepting many of the current recommendations in their entirety. We should know what evidence there is in support of these new concepts and new methods. What assumptions are involved and have they been shown to be valid? Are they stated in terms so that agronomists as well as statisticians may have an opportunity to pass judgment upon them? It would appear that agronomists have not merely a right to a convincing and intelligible answer to these questions, but rather an obligation to themselves and to the public which they serve to satisfy themselves that the answers are correct and reliable before they embark too far from the shore of proved methods.

Let us consider pseudo-factorial designs. These were first proposed about 3 years ago and are claimed to be especially efficient for testing a large number of varieties. So far as one may judge from the literature, the validity of the method of making corrections in yields or adjusting yields, a necessary step in interpreting the data, has scarcely been considered. Agronomists have had much experience, some at least unfavorable, in correcting or adjusting yields, and may well think twice before they generally adopt any arbitrary correction method without convincing evidence in its favor. Weiss and Cox (7), in a recent paper, indicate that some limitations are involved for they specifically state it is "unwise to employ this type of design when

comparing varieties which have an extremely large range in yields." Now every agronomist knows that in most tests involving a large number of varieties some are almost certain to be found that differ widely in yield; indeed, the primary purpose of most variety tests involving large numbers is to identify such varieties.

These authors indicate that the method is unsatisfactory for such tests because of the partial confounding of varietal differences with block effects. This, of course, is true whether differences between varieties are large or small. The error introduced in making yield adjustments is likewise small when yield differences are small, but has it not been overlooked that such errors become relatively more important as the need for detecting small differences increases? It seems altogether likely that, when all of the assumptions involved in pseudo-factorial experiments are realized and accounted for, much of the supposed gain in efficiency will be found to have disappeared.

Another point on which agronomists will want a convincing answer is whether interaction is a valid measure of significant differences. Most writers who have treated the subject, and these include Fisher (2), Summerby (6), Goulden (3), and Leonard and Clark (4), definitely recommend such usage with little or no specific qualifications, or infer by examples and discussion that it may be so used with impunity. Snedecor (5), on the contrary, specifically states that it is not always a valid estimate of error, although one might infer from his discussion that such is not often the case. Also, he implies that a determination of whether it is or is not a valid estimate is not difficult though he gives no clear-cut method of doing so. These citations, together with instances in the literature of uncritical usage of interaction variance as a measure of error, would seem to indicate that the conditions determining its proper use are not well understood. It is not the purpose of this paper to show how, where, or when interaction may be used, but rather to emphasize the need for critical consideration.

For this purpose two similar, hypothetical examples and two making use of actual experimental data are presented. In the first example we will suppose a variety test is conducted both on bottom land and on upland on the same farm. The individual plot yields, the average yields, the analysis of variance, standard errors, interaction, etc., are given in Table 1.

The difference in yield in Table 1, it will be noted, is in favor of variety A in both cases and on bottom land is highly significant. On upland the difference is about equal to the standard error. The practical recommendations based on this test obviously would be that variety A should be grown on bottom land, whereas on upland it would make no material difference.

Suppose, however, that our hypothetical owner insists on growing one variety only on his farm. Must we tell him, as would be necessary if we accepted what appears to be the current opinion, that no recommendation can be made merely because the variety variance is not significantly greater than variety × field interaction variance? There can be no doubt, it seems, that such an interpretation would be grossly misleading.

TABLE 1.—*Hypothetical yields of two varieties (A and B) on upland and on bottom land on the same farm with a random arrangement of the plots.*

Plot No.	Bottom land		Upland	
	Variety A	Variety B	Variety A	Variety B
1	29	16	13	9
2	30	14	9	10
3	31	12	11	11
Average	30	14	11	10
Difference	+16		+1	

Analysis of Variance

Source of variations	df	Sum of squares		Mean square	σ
Total	11		802.25		
Varieties	1	216.75		216.75	
Fields	1	396.75			
Varieties × fields	1	168.75		168.75	
		782.25	782.25		
Error	8		20.00	2.50	1.58

Example 2 (Table 2) portrays a similar situation in which, however, variety A yields better than B on bottom land as before but less on upland, the differences in both cases being significant; on the bottom land highly significant. Again, the owner insists on growing a single variety. The common sense recomendation to be made would depend on the relative proportions of bottom land and upland. If equal proportions of each, then variety A would be expected to give the largest average yield per acre for the entire acreage. Again it would appear that basing an interpretation on the ratio of variety variance to interaction variance would lead to entirely erroneous conclusions.

The third example deals with actual experimental data, *viz.*, the differences in annual yields between Thatcher and Marquis spring wheat for each of eight experiment stations in the stem-rust area of western Minnesota and the eastern Dakotas. The average gains, the standard error of these gains, and the t values are given in Table 3. The data are summarized for two periods, one up to and including 1935, for it was at about the end of 1935 that the value of Thatcher was first generally recognized and when it was first recommended for the entire area in question. The other summary is for the full period of testing up to and including 1938. The standard errors for each station were calculated by the so-called "Student's method" which, as is now well known, is in this case equivalent to variety × season interaction in an analysis of variance. It is apparent that if varietal differences had been interpreted in terms of variety × season interaction, there is only one station (Crookston) at which the data at the end of 1935 would have supported a recommendation in favor of Thatcher. Analysis of variance for the two varieties at the four

TABLE 2.—*Hypothetical yields of two varieties (A and B) on upland and on bottom land on the same farm with a random arrangement of the plots.*

Plot No.	Bottom land		Upland	
	Variety A	Variety B	Variety A	Variety B
1	29	16	9	16
2	30	14	10	12
3	31	12	11	14
Average	30	14	10	14
Difference	+16		−4	

Analysis of Variance

Source of variations	df	Sum of squared deviations		Mean square	σ
Total	11		728		
Varieties	1	108		108	
Fields	1	300			
Varieties × fields	1	300		300	
		708	708		
Error	8		20	2.50	1.58

TABLE 3.—*Yearly gains (+) and losses (−) in yield of Thatcher as compared with Marquis at indicated experiment stations.**

Year	St. Paul, Minn.	Crookston, Minn.	Waseca, Minn.	Morris, Minn.	Fargo, N. D.	Langdon, N. D.	Mandan, N. D.	Brookings, S. D.
1929	−3.2	12.6	−2.2	5.2	——	——	——	——
1930	4.6	1.4	1.8	4.4	1.2	20.8	1.5	4.9
1931	0.7	6.3	2.7	5.6	2.9	4.4	−0.7	0.8
1932	4.9	1.4	−3.7	−4.8	1.0	−0.2	4.2	−1.5
1933	3.1	1.4	1.2	——	1.0	−4.0	——	——
1934	−0.4	5.2	−2.8	1.7	−0.6	0.4	1.1	0.8
1935	21.4	17.0	21.4	29.6	19.9	16.9	16.5	20.7
1936	1.0	2.6	1.9	−0.1	3.8	−0.5	——	11.6
1937	3.9	13.3	27.4	6.2	18.1	9.7	8.6	16.2
1938	17.3	18.5	16.1	18.5	12.9	17.6	9.9	9.8
Average, 1929–35	4.4	6.5	2.6	7.0	4.2	6.4	4.5	5.1
σ_d	3.0	2.3	3.3	4.8	3.2	4.1	3.1	4.0
t	1.5	2.8	0.8	1.5	1.3	1.6	1.4	1.3
Average, 1929–38	5.3	8.0	6.4	7.4	6.7	7.8	5.9	7.9
σ_d	2.5	2.1	3.5	3.5	2.7	3.1	2.3	2.8
t	2.2	3.7	1.8	2.1	2.5	2.5	2.5	2.8

*Data secured in cooperation with the agricultural experiment stations of Minnesota, North Dakota, and South Dakota.

Minnesota stations (at which plots were arranged at random) is given in Table 4 for such use as the reader may desire to make of it.

TABLE 4.—*Analysis of variance for Thatcher and Marquis at St. Paul, Crookston, Waseca, and Morris, Minn., 1929 to 1935.*

Source of variation	d/f	Sum of squares	Mean square
Blocks	54	664.73	——
Stations	3	719.27	——
Years	6	4123.87	——
Varieties	1	1017.00	1017.00*
Stations × years	18	3361.68	——
Varieties × years	6	2190.91	365.15†
Varieties × stations	3	109.56	36.52‡
Error	70	796.16	11.37
Total	161	12983.18	

*Highly significant in relation to error variance but not significant in relation to variety × year interaction variance.
†Highly significant in relation to error variance.
‡Significant in relation to error variance.

Probably no one would insist that agronomists make no mistakes nor that Thatcher is beyond all doubts superior to Marquis for all conditions likely to be encountered in this area. On the other hand, an estimated 15,000,000 acres of Thatcher wheat, representing about 90% of the acreage devoted to hard spring wheat in the stem-rust area of Canada and the United States in 1939, must be regarded as substantial evidence that they were not wrong.

Why does the use of interaction in these examples lead to erroneous interpretations? Again it seems clearly a case of making assumptions that are not valid. Thus we tacitly assume a homogeneous population. But is it not true that the mere fact that interaction is proved to be present is in itself proof that we have a heterogeneous population and have no warrant whatever for considering it is anything else? Thus, in the first two examples, we have one population of upland fields and another of bottom land fields; not a single homogeneous population of fields as the use of interaction variance implies. Similarly, in the Marquis-Thatcher comparison, we have one population of rust years and another of non-rust years, not a single homogeneous population of all years.

Attention may now be directed to a fourth example in which the use of interaction variance supports conclusions in accord with common sense interpretations, but which illustrates (as does also the Thatcher-Marquis comparison) another important point in agronomic experimentation, *viz.*, the difficulties in properly evaluating year-to-year variations. This example consists of the average differences in yield between Kanred and Turkey winter wheat at the Kansas Experiment Station, Manhattan, Kansas, for a period of 28 years. Table 5 gives the mean difference for the first half and for the last half of the period separately; also the standard errors (calculated by Student's method) and the t values. For the first 14 years the average difference is 3.0 bushels per acre and highly significant; for the last 14 years only 0.8 bushel and far below the level of statistical significance. In other words, these data for the first 14 years whether interpreted statistically or otherwise afforded no reliable basis for predicting relative yields in the second 14-year period.

TABLE 5.—*Yearly gains (+) or losses (–) in yield of Kanred as compared with Turkey at the Kansas Agricultural Experiment Station.**

Year	Gain (+) or loss (–) of Kanred over Turkey	Year	Gain (+) or loss (–) of Kanred over Turkey
1911	3.5	1925	4.5
1912	6.6	1926	1.6
1913	3.5	1927	3.1
1914	– 0.9	1928	1.7
1915	3.0	1929	2.0
1916	11.4	1930	1.3
1917	3.5	1931	+1.1
1918	5.4	1932	–1.4
1919	–0.2	1933	–3.6
1920	1.9	1934	–1.3
1921	2.3	1935	–1.0
1922	0.0	1936	1.4
1923	0.2	1937	1.7
1924	1.2	1938	2.9
Average ...	3.0	Average .	1.0
σ_d	0.87	σ_d	0.57
t	3.45†	t	1.76‡

*Data secured in cooperation with the Kansas Agricultural Experiment Station
†Highly significant
‡Not statistically significant

The Thatcher-Marquis and the Kanred-Turkey comparisons are not isolated examples; they merely illustrate a fact well known to agronomists that yearly variations not only in absolute yields but also in relative yields are the general rule and constitute a principal problem in evaluating experimental results. To what extent and how statistical methods can be used in solving this problem is of great interest and importance to agronomists. Certainly we can have little confidence in a method which fails us in a critical situation even though it may not be misleading at other times.

The above, of course, does not mean there is no place for statistical analysis even though there may be serious limitations with respect to their use in interpreting year-to-year variations. As a matter of fact, they were useful in evaluating Thatcher and Marquis, especially in proving clearly that the difference in yield could not reasonably be explained by the plot-to-plot variation within each experimental field. They would be useful in showing that interaction is statistically significant if there is any doubt on this point. A statistical study of the Kanred-Turkey comparison year by year would no doubt be useful in determining in which years differences in yield were significant.

One might, if so disposed, follow the recommendations of a recent writer in which he stated that if in comparing two varieties it is known that one is always better than the other, we are justified in considering only one-half of the frequency curve, thereby doubling the probability, and with respect to Marquis and Thatcher show a significant difference in favor of Thatcher at the end of 1935 at all stations but one. It is a bit difficult, however, to see just what is learned by using a statistical analysis to prove that one variety is better than another when as a basis for our calculations we set up the assumption that it is better.

In concluding this portion of the discussion, it should be noted that the difficulties in using statistical methods are by no means universally ignored or overlooked. Two recent papers, in particular, by Cochran (1) and by Yates and Cochran (9), give extensive discussions of precautions that should be observed. Others might be mentioned. Perhaps they suggest a somewhat different trend in our thinking such that we may in the future expect as critical a consideration of statistical methods as we have in the past of the experiments to which they are to be applied. If so, we may confidently expect better statistical treatment of data and better interpretation of field experiments.

Be this as it may, it would seem that a correct and complete evaluation of statistical methods is not likely to be achieved until they are considered in relation to the broad objectives and methods of research that generally prevail. In agronomy there seem to be two schools of thought indicated not so much by expressed opinions or stated philosophies as by the manner in which problems are attacked. Thus we have one school which seems to be concerned only or primarily with immediately practical objectives, and little if at all with determination of principles or general relations. This school emphasizes the need of empirical trials on as extensive a scale as time and money permit, and for all conditions where it is anticipated the results will be applied. If funds were available, such persons presumably would have variety trials, fertilizer experiments, soil, culture, and rotation tests, etc., repeated a number of times in every county in the United States where such problems were thought to exist. Data derived from such experiments, if the plots were arranged at random, presumably would be considered ideal for statistical treatment. Research, taken as a whole, has been so thoroughly worth while that such experiments, though expensive, would no doubt be worth all they cost, but it may seriously be questioned whether they would constitute a wise expenditure of public funds.

Science, in general, has made most progress in quite a different way, and it is difficult to believe that agronomy is so different that the same methods are not applicable. Important discoveries have been made by empirical trials, it is true, but in general science has used this method as a last resort and not by preference. The more general approach has had as a fundamental objective the determination of cause and effect relations so that predictions might be made not so much on the basis of statistical calculations as from established principles carefully verified.

This does not in any way preclude extensive experiments; on the contrary a certain number of experiments conducted throughout a wide range of conditions are necessary in order to establish principles on a sound basis. Neither does it preclude statistical analysis of data. On the contrary, again, such may be even more necessary and valuable than in the former case. The point is that in the scientific method of attack statistical methods assume their proper role as tools to be used if and when they are needed and suitable for the purpose. They may not be needed at all; for some purposes and occasions they may be indispensable.

Thus with respect to the Marquis-Thatcher comparison, we believe Thatcher is a superior variety simply because, as a result of nearly 75 years' experience in growing spring wheat and numerous greenhouse, laboratory, and field experiments and observations, we know (a) that stem rust is a very important factor in limiting yields; (b) that Thatcher is highly resistant to stem rust, that Marquis is susceptible, and that the former yields relatively much more when stem rust prevails; and (c) that in non-rust years Thatcher yields substantially the same as Marquis. Granting these facts, it requires no fine-spun logic to reach the conclusion that Thatcher rather than Marquis should be grown. Statistical methods were not necessary to demonstrate the importance of stem rust nor to prove that Thatcher is more resistant to stem rust than is Marquis. They were useful in determining whether yields were substantially different in non-stem-rust years. It would not be difficult to conceive of a situation where statistical methods would be very valuable if not essential, as for example, in determining whether differences in yield due to some disease having a minor effect on yield were significant. The demonstration of such a relation might be very important if the disease were widespread.

The approach by the scientific method is especially important in relation to future progress. Thus we know that Thatcher is susceptible to leaf rust. It is possible that wide distribution of a susceptible variety may so favor the spread of leaf rust that much of the advantage of growing Thatcher may be nullified. Fortunately, and thanks to the scientific method, this problem has been anticipated and as a result there are now being tested literally thousands of selections and varieties that are resistant not only to stem rust, but also to leaf rust and to other diseases known to be important factors in determining yields.

Also it was discovered many years ago that Kanred winter wheat is now susceptible to the prevailing races of leaf rust though resistant to the races that were common when it was first grown. Probably much of the difference in response in the two 14-year periods is related to these facts. Here again the knowledge of the causal relations suggested the remedy and as a result varieties are now being grown that are resistant to leaf rust. We are no longer greatly concerned, from a strictly practical point of view, as to whether Thatcher is superior to Marquis or Kanred to Turkey. Our real anxiety is whether the numerous new varieties that have been developed in recent years are superior. In settling these questions, statistical methods will without doubt be used in so far as they can contribute to sound and reliable conclusions.

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NOTE

GERMINATION OF SEED OF GOOSEGRASS, *ELEUSINE INDICA*

DURING the last several years we have carried on work on the germination requirements of various weed seeds. Although the work with goosegrass, *Eleusine indica* (L) Gaertn., involved approximately 140 tests of 100 seeds each with three samples collected in successive years, it is not considered that the problem is completed. Since probably it will be impossible for the authors to complete this work, a summary of the results obtained is given in the hope it may serve as a starting point for others.

Germination was negligible at 10°, 15°, and 20° C, constant temperature, and at 15° to 25° alternating temperature.[1] When 0.2% solution of potassium nitrate was used to moisten the substratum, germination of fresh seed was 90% or above after 14 to 56 days in the germinator at the alternations 20° to 35°, 20° to 40°, or 25° to 40°. Germination at the alternating temperature 20° to 30° with light, was slower and with two of the three samples less complete. When tested with water, germination was poor at 20° to 30°. At the higher temperatures germination with water was slower than with potassium nitrate and often the final germination with water was lower (Table 1).

Seed tested approximately 2 months after collection showed the same response to temperature as when freshly harvested.

Total exclusion of light had little effect on germination when potassium nitrate was used but caused a reduction in germination when water was used to moisten the substratum.

Prechilling the seed at 3° C for 2 to 8 weeks was not beneficial.

Scarification with emery paper caused earlier germination but even after scarification (the pericarp is thin and papery so that it is the true seed coat that is affected) germination was benefitted by potassium nitrate and high temperature.

In conclusion, 20° to 35° C or 25° to 40° C alternations seem to be the most favorable temperatures for germination. Potassium nitrate is beneficial and light is needed if potassium nitrate is not used. The time for complete germination at 20° to 35° C with potassium nitrate

[1]For all alternating temperature conditions, the seed was kept for approximately 17 hours at the first temperature mentioned and for 7 hours at the second temperature.

TABLE 1.—*Germination of freshly harvested seed of Eleusine indica at four temperature alternations, averages of duplicate tests of 100 seeds each.*

Sample No.	Percentage germination in 14 days at temperature alternation indicated				Percentage germination in 56 days at temperature alternation indicated			
	20°–30° C With light	20°–35° C	20°–40° C	25°–40° C	20°–30° C With light	20°–35° C	20°–40° C	25°–40° C
	Water used to moisten substratum							
440	6 0	66.0	46.5	34.0	28 5	82.0	86.5	36.5
397	7.5	68.0	60 0	95.0	16 0	92.0	91 5	95.0
Mean	6.75	67.0	53.25	64 5	22.25	87.0	89.0	65.75
	Potassium nitrate used to moisten substratum							
440	25.0	76.0	42 5	92 5	82.5	93 5	94.0	95 5
397	52.0	95 0	54.0	98 5	98 0	98.5	90.0	98.5
Mean	38.5	85.5	48.25	95.5	90 25	96.0	92.0	97.0
Means	22 62	76.25	50.75	80 0	56.25	91.5	90 5	81.37

varied from 28 to 84 days, depending upon the maturity and the age of the seed.—EBEN H. TOOLE and VIVIAN K. TOOLE, *Division of Fruit and Vegetable Crops and Diseases, U. S. Dept. of Agriculture, Beltsville, Md.*

AGRONOMIC AFFAIRS

RECEIPTS AND DISBURSEMENTS FOR MEETINGS OF THE THIRD COMMISSION OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE

THE following statement, submitted by Dr. S. A. Waksman, covers the receipts and expenditures in connection with the meetings of the Third Commission of the International Society of Soil Science held at New Brunswick, N. J., August 30 to September 1, 1939.

RECEIPTS

Contributions by outside organizations, as listed in Vol A..	$1,100.00	
Contributions of the N. J. Agr. Exp. Station	100.00	
Contributions of College of Agriculture, Rutgers University, to cover cost of banquet..........................	189.75	
Contribution of Soil Science Society of America (to cover bill for Vol. B)................................	404.00	
Registration................................	117.00	
Tickets for supper, dormitory accommodations, and miscellaneous................................	276.00	
Sale of reprints................................	352.60	
Sale of Volumes A and B................................	7.50	
		$2,546.85

DISBURSEMENTS

Dormitory rent	$ 243.00	
Supper, tea, and miscellaneous	109.50	
Banquet given by Rutgers University	189.75	
Editorial work on Volumes A and B	45.00	
Printing of program	22.50	
Printing of Vol A	944.90	
Printing of Vol. B	404.00	
Cost of reprints	360.00	
Mailing charges of Volumes A and B	135.61	
Shipment of remaining Volumes to Dr. Pohlman	9.41	
Cash on hand	83.18	
		$2,546.85

SUMMER MEETING OF CORN BELT SECTION

THE summer field meeting of the Corn Belt Section of the American Society of Agronomy is scheduled for September 4, 5, and 6 at the Iowa State College, Ames, Iowa. Registration will be in the late afternoon of Wednesday, September 4, with a general meeting and group conferences in the evening. On Thursday the agronomic research work at Ames will be seen in the field with a dinner in the evening. On Friday the group will split into different parties on the basis of primary interests. Plans are underway for a grasslands conference in conjunction with the meeting, similar to that held at Wooster, Ohio, last summer.

SUMMER MEETING OF SOUTHERN SECTION

THE summer meeting of the Southern Section of the American Society of Agronomy will be held in Louisiana August 6 to 9 under the supervision of the Crops and Soils Department of the Louisiana Agricultural Experiment Station.

An automobile trip through the state is being planned for the purpose of visiting substations and experimental fields at which problems of soil fertility and fertilizers and the breeding and culture of cotton, corn, forage crops, rice, and sugarcane are being studied.

For further details communicate with Dr. Franklin L. Davis, Crops and Soils Department, Louisiana Agricultural Experiment Station, University, La.

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THE RELATIONSHIP BETWEEN LEAF AREA AND YIELD OF THE FIELD BEAN WITH A STATISTICAL STUDY OF METHODS FOR DETERMINING LEAF AREA[1]

J. F. DAVIS[2]

SINCE 1921 considerable emphasis has been given to fertility studies with reference to the field bean, but rather discouraging results have been obtained due to the inconsistency of response to the same analysis of fertilizer both during the same season and from year to year on the same soil type. However, a few remarks as to the growth habit of the bean plant in Michigan might tend to clarify these apparent discrepancies in the results obtained.

The bean-producing area is located in the central-eastern part of the Lower Peninsula, known locally as the Saginaw Valley and Thumb area. The soils in this area are predominately fertile loams and silt loams. Higher yields of beans are secured from this area than from other areas in Michigan although the soil types are very similar. This situation would indicate that factors other than soil fertility materially affect the growth and maturity of the crop.

The length of growing period of the field bean is approximately three months. The beans are planted normally about the first week in June and harvested during the first part of September. As the crop must mature in a relatively short period of time, climatic conditions play a very important part in the development of the plant. The crop is susceptible to late spring and early fall frosts and is extremely sensitive to adverse moisture conditions. At blossoming time humidity and temperature conditions appear to control the number of pods that are set. Under unfavorable temperature and moisture conditions a number of the blossoms are frequently blasted, thus resulting in a material decrease in the yield. It is frequently observed early in the season that plants on fertilized plats make considerably more vegetative growth than do plants on plats receiving no fertilizer. This difference in growth appears gradually to diminish. At the time of blossoming the difference is very small, and at harvest time the yields

[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Authorized for publication by the Director as Journal Article No. 390 (n. s.) of the Michigan Agricultural Experiment Station. Received for publication December 29, 1939.

[2]Assistant in Soils. The writer is indebted to Professor W. D. Baten for assistance in the preparation of this manuscript.

from untreated plats do not differ greatly in many cases from yields of fertilized plats. The difference in early growth leads to erroneous opinions as to the actual benefit derived from the use of fertilizers due to the fact that this increase in vegetative growth is not always reflected in the yield of beans at the time of harvest. In view of these circumstances the following study was begun to obtain more information regarding the effect of fertilizer on factors other than yield.

PROCEDURE

For part of this work it was thought advisable to secure, at the beginning of the blooming period, the leaf area for a number of bean plants. These first leaf area measurements were made with a planimeter. However, this method required so much time that it was soon deemed advisable to devise some quicker method of measurement. It was believed that if the product of the length and width measurements of the leaflets were multiplied by a suitable factor the result would represent a reliable estimate of the leaf area. In 1935 the length and width measurements of 360 leaflets measured with a planimeter were taken by laying the pressed leaflet on cross section paper. The length and width measurements were expressed in 1/20 inch units, corresponding to the units on the cross section paper. The two outside leaflets of a bean leaf are irregular in form and in many cases the midrib is distinctly curved which is coincident with unequal development of the two leaflet lobes (Fig. 1). The center leaflet on the contrary, is regular in form, and due to this fact it would appear logical that a higher correlation might exist between leaflet area and length and width measurements of this leaflet than in the case of the irregularly shaped outside leaflets. Leaflet areas were predicted from the length times width of the leaflets by three different methods.

DISCUSSION

The predicting equations are presented in Table 1. First, the regression equation of area, as might be determined by the planimeter, on length times width for all the leaflets was found by the least squares method to be $A = .001475\ L \times W + .07$.[3]

TABLE 1.—*Four equations for predicting leaf or leaflet area from the length times the width of bean leaflets.*

Equation	How constants in equation were obtained
$A = .001475\ L \times W + .07$	Least squares
$A^* = .001582\ L \times W$	Average of ratios of form $\left(\frac{\text{Leaflet area}}{L \times W}\right)$ for all leaflets by least square method
$A = .001433\ L \times W$	Same as above; only center leaflets used
$A = .004517\ L \times W$	Same as above; center leaflets used; Area refers to total leaf area rather than leaflet area

*Since a bean leaflet resembles to some extent an ellipse in form, we would expect a factor calculated from the ratio of area/length times width to approximate the figure 0.7854, since the area of an ellipse is expressed by the formula Area = 0.7854 L×W. If the factor 0.001582 is multiplied by 400, we arrive at the figure 0.6328 which is comparable to the value 0.7854. It is necessary to multiply the factor expressed in the equation by 400 because the factor was calculated in 1/20 inch units corresponding to the units on the cross section paper.

[3]L and W are expressed as 1/20 inch units corresponding to the scale of the cross section paper used in taking the measurements.

A second possibly suitable factor was found by averaging the 360 ratios of the form, area/length×width. This average was .001582 and the predicting equation became A = .001582 L×W. A third factor, .001433, was similarly found by averaging the above ratios for the center leaflet only. To test these predicting equations, 50 of the 360 leaflets were selected at random and their areas as calculated by the three methods were compared with the planimeter areas.

Significant differences were found between the calculated areas and planimeter areas in the first two methods, but not in the third method where only the center leaflets were used. The mean differences, their standard errors, and "t" values are given in Table 2. In view of the fact that a very close agreement resulted between the planimeter measurements and estimated areas when the factor obtained by averaging the ratios of the form, area/length×width of the center leaflet, was used, the use of the relationship between the entire leaf area and the length×width measurement of the center leaflet should further facilitate the work in leaf area studies.

FIG. 1.—A bean leaf consists of three leaflets, the center one of which is regular in form.

TABLE 2.—*Statistical constants obtained from calculated areas of bean leaflets when compared with the area computed from the use of the planimeter.*

	Mean difference	Standard error of mean difference	"t"	"t" 5% point
A = .001475 L × W + .07	.1286	.0339	3.794	2.008
A = .001582 L × W Leaflet Area/(L × W) all leaflets	.2490	.0384	6.484	2.008
A = .001433 L × W Leaflet Area/(L × W) center leaflets	.0152	.0335	0.454	2.008
A = .004517 L × W Total leaf area/(L × W) center leaflets	.06832	.05992	1.140	1.971

In 1936, the average of 226 ratios of the form, total leaf area/length times width of the center leaflet, was found to be .004517 (Table 1). The total leaf areas found by this method agree essentially with the planimeter areas. The mean difference and its standard error and "t" value have been presented in Table 2.

The average total leaf area for the 226 leaves was found to be 6.93 square inches with an average leaflet area of 2.31 square inches. Based on these values the mean differences in Table 2 calculated from factors (0.06832 square inch and 0.0152 square inch) represent 0.98% and 0.66%, respectively, of the average leaf and leaflet area, which is a very low percentage of error.

In arriving at a suitable factor for estimating leaf area it would be desirable to know the minimum number of leaves necessary to

measure in order that a valid estimate of the factor be obtained. This minimum number will be obtained from measurements of 226 leaves as an illustration. The mean and standard deviation of the ratios, area/length×width, were obtained for these 226 leaves. From this parent population or universe one may sample and find the average of the ratios and compare this average with the average of the ratios of the 226 leaves. If a small number of leaves is used in the sample, one can expect a larger deviation from the average of the ratios of the 226 leaves than when a larger number is used. The number in the sample can be obtained from Carver's formula if one assumes that the average of the ratios from the sample should lie within certain limits of the means of the parent population.[4]

The mean and standard deviation of the 226 ratios are, respectively, 0.454 and 0.065.

If one assumes that the mean of the ratios from the sample should lie within 0.01 of the mean on the average about 68 times in 100, the number is obtained from the formula due to Carver:

$$\sigma_z = \sqrt{\frac{S-N}{N\ (S-1)}} \cdot \sigma_{\text{parent}},$$

where S is the number in the parent, N is the number in the sample, and σ_z is the standard deviation of the distribution made up of all possible sample averages. According to this formula and the accepted limits $N \geq 36$ leaves.

$$\sigma_z = \sqrt{\frac{226-N}{N\ (S-1)}}\ .065 = .01$$

To check whether or not theory is in keeping with practice in sampling, two samples of 45 leaves and one of 25 leaves were taken from the 226. The means from the samples of 45 were within the limits taken in finding N; the mean of the ratios from the 25 leaves was not within the limits. This suggests that for this material any sample containing 36 or more leaves will give an average within 0.01 of the mean of the 226 about 68% of the times, or since the factor for finding the area is an average of ratios, this factor within the limits suggested can be obtained from 36 or more leaves.

Since the method described appeared to be rapid enough for practical use and at the same time sufficiently accurate to give reliable measurements, bean plants were selected at the beginning of the blossoming period from plats receiving an application of 300 pounds of a 4–16–4 fertilizer and from corresponding untreated plats. Ten large plants representing as nearly as possible the average large size plants and 10 small plants representing the average small plants were selected. At the same time 20 of the large and small plants were tagged to be harvested individually at time of maturity. This work was carried out in three different fields, two of which were located in Tuscola County and one in Sanilac County. Three soil types, Brooks-

[4]CARVER, H. C. Annals of Mathematical Statistics. Vol. 1. 1930.
BATEN, W. D. The Tôhoku Mathematical Journal. Vol. 36. 1933.
RICHARDSON, C. H. Statistics of Sampling. Dissertation at University of Mich. 1936.

ton silt loam, Miami silt loam, and Napanee loam, were the soils on which the fields were located. The idea in mind was to determine whether or not any significant differences in leaf area existed between bean plants on fertilized plats and those on untreated plats, and if a difference existed whether or not this difference would be reflected in the yield of individual plants, thus giving some indication of the effect of leaf area on the yield of a bean plant. The mean leaf areas and yields with their respective standard errors were computed, together with the mean difference of leaf areas and yields of the plants from the fertilized and untreated plats. The leaf area is recorded in square inches and the yields in grams of dry beans per plant.

The data secured from the leaf area measurements are presented in Tables 3 and 4. The data show that extreme variations existed in

TABLE 3 —*Mean leaf areas of bean plants from fertilized and untreated plants.**

Soil type	Large plants		Small plants	
	Fertilized	Untreated	Fertilized	Untreated
Brookston silt loam	451.0±24.4	439.1±46.0	165.1±12.4	158.6±11.1
Miami silt loam. . . .	355.5±26.4	260.1±28.7	121.4± 8.4	109.6± 9.7
Napanee silt loam .	204.4±14.1	174.3±16.6	99.5± 6.7	64.8± 4.7

*Leaf areas expressed in square inches per plant.

TABLE 4. —*Mean differences between leaf areas of bean plants from fertilized and untreated plats.*

Size of plants	Brookston silt loam	Miami silt loam	Napanee silt loam
Large . .	11.9±52.1	95.4±39.0	30.1±21.8
Small. . .	6.5±16.6	11.8±12.9	34.7± 8.2

the leaf area of plants growing on different soil types. It is not unlikely that location was also a factor in determining the leaf area of plants since each soil type was in a different location. The Brookston soil was located near Unionville, the Miami near Cass City, and the Napanee near Sandusky. It would be impossible to segregate the effects due to soil type and those due to location in this particular study. In the case of fertilized plats the large plants grown on the Brookston soil had an average leaf area of 451.0±24.4 square inches compared to 355.5±26.4 square inches for plants on the Miami soil and 204.4±14.1 square inches for plants grown on Napanee soil. The corresponding leaf areas for plants from untreated plats were 439.1±46.0, 260.1±28.7, and 174.3±16.6 square inches, respectively. The mean difference between the leaf area of large plants from the treated and untreated Miami soil was significant. Similarly the small plants from the fertilized plats had a leaf area of 165.1±12.4, 121.4±8.4, and 99.5±6.7 square inches as compared to 158.6±11.1, 109.6±9.7, and 64.8±4.7 square inches for plants from unfertilized plats on the Brookston ,Miami, and Napanee soils respectively. In these comparisons only the mean difference in leaf area of plants from treated and the untreated plats on the Napanee soil was found to be signifi-

cant. Attention should be called to the fact that in every instance the leaf area of the plants from fertilized plats was greater than the leaf area from the untreated plats. As significant differences in leaf area were obtained between the large plants from fertilized and unfertilized Miami soil and between the leaf areas of small plants on the treated and untreated Napanee soil, the results from Tables 3 and 4 would suggest that if a sufficient number of plants from each plat had been measured, significant differences might have been obtained in all cases.

As shown in Tables 5 and 6, no significant differences were found to exist between the yields of plants of corresponding size from treated and untreated plats on the different soil types. With the exception of the one case on the Brookston soil in which the yield from the fertilized plat was less than the yield from the untreated plat, all yields of plants from fertilized plats were higher indicating again that if a sufficient number of plants had been used significant difference in yield might have resulted. The data appear to indicate that there is a tendency for a positive correlation to exist between mean leaf area and mean yield and that with an increase in leaf area an increase in yield might result. However, it does not necessarily follow that correlation within plats is the same as correlation between the means for the different variables, and it would be necessary to repeat the experiment using a larger number of plants before definite conclusions could be drawn.

TABLE 5.—*Mean yields of bean plants from fertilized and untreated plats.**

Soil types	Large plants		Small plants	
	Fertilized	Untreated	Fertilized	Untreated
Brookston silt loam . .	22.4±1.43	20.5±1.62	9.3±1.23	9.9±0.73
Miami silt loam.	23.4±2.12	19.0±2.00	9.3±1.24	6.7±0.46
Napanee silt loam. . . .	12.6±0.77	12.5±0.84	5.3±0.39	4.4±0.45

*Yields expressed in grams per plant.

TABLE 6.—*Mean differences between yields of bean plants from fertilized and untreated plats.*

Size of plants	Brookston silt loam	Miami silt loam	Napanee silt loam
Large.	1.9±2.60	4.4±2.60	0.1±1.14
Small.	−0.6±1.43	2.6±1.32	0.9±0.60

SUMMARY

The data presented show that a close approximation exists between leaf areas measured with a planimeter and leaf areas estimated from the use of factors obtained from length and width measurements of the center leaflets.

Total leaf area $= .004517\ L \times W$ (*of center leaflet*) is the best equation of the four because of the time saved since only the length and width of the center leaflet are necessary.

It would be possible to secure the leaf area of a bean plant without necessitating the removal of the leaves. The only measurements required would be the length and width measurements of the center leaflet.

The data show that the measurements of 36 leaves are sufficient to arrive at a suitable factor.

It seems possible that this method of securing leaf areas need not be limited to the bean plant but could be used with any plant with similar leaf habits providing a suitable factor were calculated.

In all instances, plants both large and small, from fertilized plats, had a greater average leaf area than plants from untreated plats. However, these differences were not found to be significant except in one case in the large plants and one in the small plants, but since all of the differences were in favor of the fertilized plats the results indicate a tendency for plants from fertilized plats to have greater leaf area than plants from untreated plats.

Similarly the yields of plants from the fertilized plats were greater than those from unfertilized plats with one exception, but again these differences were not great enough to be significant with the number of plants used.

In either case the indications are that if a sufficient number of plants had been used significant differences might have resulted.

With the inherent variability that is evident between individual plants the data bring out very clearly the necessity of using a number of plants sufficiently large to overcome this variability before a definite conclusion can be reached.

NATURAL SUCCESSION OF VEGETATION ON ABANDONED FARM LANDS IN TETON COUNTY, MONTANA[1]

B. IRA JUDD[2]

MUCH interest has been manifest during the past few years in the process of natural succession of vegetation on abandoned farm lands. In view of this, various investigators (1, 3, 4, 6, 7)[3] have made this process the object of careful study. This paper presents further information on natural revegetation of previously cultivated land representing a portion of the Great Plains heretofore unreported.

Time did not permit the taking of quadrat counts on the fields studied, but the vegetation of each field was checked, listing the species encountered and an attempt made to give the relative frequency of each species.

LOCATION AND DESCRIPTION OF AREA

The observations were made in August 1939 in Teton County, Montana, located in the northwestern part of the state southeast of Glacier National Park. It is bounded on the south by Sun River and on the west by the continental divide and the Sun River (Fig. 1).

The greater part of Teton County covers a transitional area between the Great Plains to the east and mountains to the west. The mountains, formed by a fault, rise abruptly and are without a distinct foothill section. Gravel-capped plateaus traversed by wide stream valleys and often eroded into flat-topped gravelly ridges extend east from the mountains for 40 miles. These plateaus have plain surfaces and slope east from elevations of 4,800 to 5,100 feet down to 4,000 to 3,900 feet. It is on these plateaus that most of the abandoned fields are located.

The climate of Teton County is semi-arid. It is influenced by the varying altitude and by mountains to the west. The area is subjected to great temperature extremes with a mean annual temperature of 42.7° F at Choteau. The mean annual precipitation at the same station is approximately 13.48 inches (Table 1). Sixty-five to 75% of the total annual rainfall is received largely in small torrential showers which cause considerable run-off in the more rolling sections. The county is subject to brisk westerly and southwesterly winds which are usually stronger during the early spring months, and in dry seasons considerable wind erosion and crop damage occurs.

In spite of the fact that observations were made during one month (August) only, it is felt that the vegetation found was representative. In the first place, little attention can be paid to the annuals since no fields abandoned one year were found. Secondly, because of the rather short growing season of 110 days (5), one would not expect a seasonal

[1]Contribution from the Department of Agriculture, Arizona State Teachers College, Tempe, Ariz. Received for publication January 29, 1940.

[2]Head of Department. Acknowledgment for constructive suggestions is made to Dr. Frederic E. Clements.

[3]Figures in parenthesis refer to "Literature Cited", p. 336.

TABLE 1.—*Precipitation and temperature records by months at Choteau, Montana.*

Month	Precipitation, inches*	Temperature, °F†		
		Mean	Absolute maximum	Absolute minimum
December ..	0.52	24.5°	78°	−28°
January ..	0.63	20.6°	79°	−42°
February. .	0.52	22.6°	64°	−40°
March	0.76	21.8°	82°	−28°
April...	0.82	42.4°	85°	−9°
May ...	2.01	51.4°	92°	18°
June .	3.01	59.5°	96°	28°
July	1.77	65.1°	101°	34°
August......	1.01	63.1°	98°	29°
September ..	1.16	64.4°	92°	10°
October ..	0.60	44.4°	86°	−15°
November ..	0.67	33.2°	77°	−25°
Annual .	13.48	42.7°	101°	−42°

*Average for a period of 24 years, 1906–30
†Average for a period of 40 years, 1890–1930.

variation of annuals. The perennial vegetation will not change abruptly seasonally unless some disturbance factor enters.

The soils of the areas studied were, for the most part, shallow gravelly or stony loams underlain by gravel. The soil would begin to drift after the original root fiber had been destroyed, leaving the stones more prominent (Figs. 2 and 3). The torrential nature of the rainfall coupled with the fact that 73% or 9.78 inches of the annual precipitation comes between April 1 and September 30 (5) also aggravates the erosion problem.

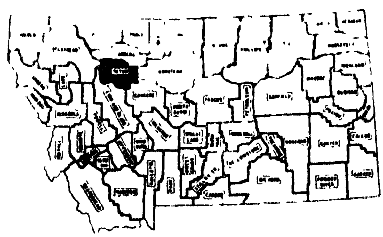

FIG. 1.—Map showing geographic location of Teton County, Montana.

Although no specific fields were found which had been abandoned one year, from observations of fields being fallowed such plants as gumweed, *Grindelia squarrosa* (Pursh.) Dunal; tumbling mustard, *Sisymbrium altissimum* L., the sunflowers, *Helianthus* spp. L.; and Russian thistle, *Salsola pestifer* A. Nels., were the most common pioneer invaders.

RESULTS

Field 2a.[4]—This field had been broken about 1930 and farmed to grain crops until 1937 when it was abandoned. Gumweed was the most conspicuous forb. There was also a good covering of small Russian thistle plants. Less common forbs were mountain sage, *Artemisia frigida* Willd., and skeleton weed, *Lygodesmia juncea*

[4]Figures in field numbers refer to number of years abandoned.

FIG. 2.—Typical surface soil conditions on an abandoned field. Stones are prominent after top soil has eroded away.

(Pursh.) D. Don. A few plants of western needlegrass, *Stipa comata* Trin. & Rupr., and green needlegrass, *Stipa viridula* Trin., were scattered throughout.

Field 4a.— This was originally broken in 1914 and farmed principally to grain crops until 1935 when it was abandoned. There was an excellent covering of weeds comprising such species as mountain sage, Russian thistle, snakeweed, *Gutierrezia sarothrae* (Pursh.) Britton & Rusby, wild rose, *Rosa* sp. (Tourn.) L, and skeleton weed. A few plants of foxtail, *Setaria viridis* (L.) Biarxv, and of western needlegrass were sparsely interspersed with the forbs.

Field 4b. This was originally broken in 1918 and farmed to small grain crops and corn until 1935 when it was abandoned. It was covered principally by gumweed and mountain sage. In addition there were a number of snakeweed and red mallow, *Sphaeralcea coccinea* (Nutt.) Rydb., plants. Spots of green needlegrass, western needlegrass, and western wheat grass, *Agropyron smithii* Rydb., were scattered over the entire area.

Field 6a.- This field was broken in 1918 and farmed to small grain until 1933, when it was abandoned. It was covered principally with Russian thistle plants. Other forbs were red mallow, mountain sage, tumbling mustard, gumweed, and goldenrod, *Solidago* sp. L. Plants of western needlegrass and mats of western wheat grass were interspersed with the forbs. Recovery seemed to be impeded because of overgrazing.

Fields 7a and b.—These areas had both been handled rather similarly and the stage of recovery was about the same. The grasses in terms of composition were in about the same proportions as the forbs. Western needlegrass was the most common. Western wheat grass, blue grama, *Bouteloua gracilis* (H. B. K.) Lag., and June grass, *Koeleria cristata* Pers., were also found, though in lesser abundance than the western needlegrass, decreasing in the order named. The perennial forbs, such as mountain sage, snakeweed, and goldenrod and the biennial forb gumweed were more common than the annual weeds.

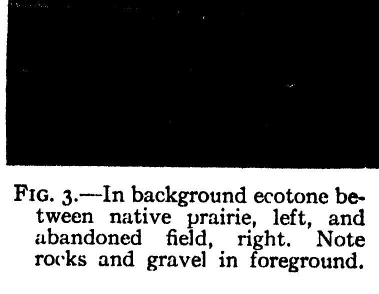

FIG. 3.—In background ecotone between native prairie, left, and abandoned field, right. Note rocks and gravel in foreground.

Field 8a.—This was broken in

1917 and farmed to small grains until 1931, when it was abandoned. There was a good covering of western needlegrass with some June grass, foxtail, western wheat grass and a few plants of blue grama and green needlegrass. The grasses were in the majority. Such forbs as mountain sage, skeleton weed, snakeweed, and cat's paws, *Antennaria compestris* Rydb., were most common.

Field 8b.- This field was originally broken in 1914 and abandoned in 1931. Because of overgrazing mountain sage was the most conspicuous type of vegetation with considerable wild roses. Other forbs were goldenrod, snakeweed, and gumweed. Although the grasses were in a minority there were a large number of species present. Blue grama, western needle, western wheat grass with some plains muhly, *Muhlenbergia cuspidata* (Torr.) Rydb., were common, the first three species being in about equal abundance.

Field 10a. This area was originally plowed in 1927, planted to wheat, disked in 1928 and again sown to wheat, after which it was abandoned. It had a good covering of grasses including western wheat grass, western needlegrass, blue grama, and June grass. Although the grasses were in the majority, such forbs as goldenrod, mountain sage, snakeweed, canada fleabane, *Erigeron canadensis* L., and *Evolvolus* sp. L., were also found.

Field 11a - This was broken out in 1917 and farmed principally to grain crops until 1928, when it was abandoned. The soil was gravelly. Western needlegrass was most common, with western wheat grass the second most common grass. A few plants of June grass were found Mountain sage was the most prominent forb. Others were gumweed, snakeweed, sunflower, and red mallow. This field had been heavily overgrazed hence succession was retarded.

Field 12a. This was broken in 1919 and farmed to grain crops until 1927, when it was abandoned. The most conspicuous forb was mountain sage, other forbs being gumweed, snakeweed, and cinquefoil, *Potentilla* sp. L. Western wheat grass and bluebunch wheat grass, *Agropyron spicatum* (Pursh.) Scribn. & Smith, were the most common grasses with some purple three-awn, *Aristida purpurea* Nutt., and bottlebrush, *Sitanion hystrix* (Nutt.) J. G. Smith, being intermixed. This area had been badly overgrazed.

Field 13a.— This area was broken in 1923, sown to oats two years followed by sweet clover, after which it was abandoned. The sweet clover had persisted and was rather common. Western wheat grass and western needlegrasses were also common. On the sandier spots sand reedgrass, *Calamovilfa longifolia* (Hook) Scribn., was found. Relatively few forbs were present.

Field 13b.—This field was broken in 1918 and farmed to grain crops until 1926, when it was abandoned. The grasses seem to be in the majority. Western needlegrass and bluebunch wheat grass were the most common with some western wheat grass, June grass, three-awn, and blue grama being present. Mountain sage and goldenrod were the most common forbs.

Field 16a.—This field was broken in 1917 and farmed to grain crops until 1923, when it was abandoned. It had a good covering of western wheat grass, bluebunch wheat grass, June grass and western needle-

grasses. Such forbs as snakeweed, mountain sage, goldenrod, blazing star, *Liatris* sp. Schreb, gumweed, and cinquefoil were common.

Field 16b.—This had a similar cover with the addition of blue grama, which was common.

Field 17a.—This was broken in 1915 and farmed to small grains until 1922, when it was abandoned. The grasses were by far in the majority with bluebunch wheat grass, western wheat grass, and western needlegrass being common. Some blue grama and muhlenbergia were also found. Cinquefoil and mountain sage were the most common forbs.

Field 17b.—This field, which had been in cultivation three years before abandonment, supported about the same type of vegetation as 17a; however, blue grama was more prevalent with the addition of some three-awn grass.

Field 18a.—This field was broken in 1917 and farmed to grain crops until 1921, when it was abandoned. There was a good stand of grasses, including June, western needlegrass, western wheat grass, bluebunch wheat grass, and blue grama. Sandreed grass was found on the sandy spots. Mountain sage was the principal forb.

Field 19a.—This was originally broken in 1916 and abandoned in 1920. There was an excellent covering of grasses closely approaching native prairie conditions. The covering was composed of western needlegrass, green needlegrass, western wheat grass, bluebunch wheat grass, June grass, and blue grama. The principal forbs were mountain sage, snakeweed, goldenrod, and cinquefoil. Three other fields abandoned 19 years were studied. The grass covering had about the same density in these as in 19a with the species being about the same.

Field 20a.—This field was broken in 1915 and farmed to small grains until 1919, when it was abandoned. There was an excellent stand of grass which gave the appearance of a recovery nearly equal to native conditions. Western wheat grass, June grass, blue grama, western needlegrass, and bluebunch wheat grass were found in about the same proportion as in native prairie. The forbs consisted principally of mountain sage, snakeweed, and gumweed.

Field 20b.—This area supported practically the same vegetation as 20a with the addition of some sedge (Niggerwool) *Carex filifolia* L. Nutt.

Field 21a.—This was broken in 1915 and farmed to grain crops until 1918 when it was abandoned. The grasses were the most prevalent type of vegetation comprising the same species mentioned in field 20a. Cinquefoil and snakeweed were in about the same proportion as in the native prairie.

Field 22a.—This field was originally broken in 1914 and abandoned in 1917. It had an excellent covering of the climax grasses as mentioned in field 20a. Except for occasional spots of mountain sage this field was comparable to native prairie.

GENERAL DISCUSSION

From the foregoing discussions of abandoned fields, variations in the amount of re-vegetation can be noted. Since most of the fields

had been subjected to wind erosion, succession was more or less erratic and was correspondingly delayed. For the purpose of clarity it might be well to classify the succession arbitrarily into stages.

The primary or annual weed stage is found on fields abandoned from one to three or more years, depending on factors which will be discussed below. Any plants of the later stages of succession would grow here, but those best adapted to seed the new area rapidly enter first. It is natural, therefore, that the first stage should be a weed stage. The plants are scattered, and in dry years are small. The principal species which constitute this stage are the following weeds: *Grindelia squarrosa*, *Helianthus*, spp., *Lygodesmia juncea*, *Salsola pestifer*, *Sisymbrium altissimum*, and *Setaria viridis*.

The second, or mixed annual-perennial stage, may be found to occur on fields abandoned from two to four or more years. Here the species which enter in the first stage reach their greatest development and begin to disappear. During the latter part of this stage such grasses as *Agropyron smithii*, *Stipa comata*, *S. viridula*, *Sitanion hystrix*, and *Aristida purpurea* begin to assume importance. Perennial forbs, such as *Gutierrezia sarothrae*, *Liatris* sp., *Potentilla* sp., *Rosa* sp., *Sphaeralcea coccinea*, and *Artemisia frigida*, are prominent. As the stage advances the grasses assume more importance.

The third or perennial stage occurs in the fields abandoned from three to eight or more years. Here the various grasses are beginning to exert dominance and to form definite alternes. *Bouteloua gracilis*, *Koeleria cristata*, *Muhlenbergia cuspidata*, and *Agropyron spicatum* make their entry into the succession. The first three mentioned made their first appearance at about the seventh year of abandonment, increasing in importance as the period of abandonment increases. *Agropyron spicatum* was first found on fields abandoned for 12 years, giving one the impression that it enters the succession later than most of the other climax species. This late appearance may be ascribed to its being the dominant in the Palouse prairie which is marked by a generally higher rainfall. *Bouteloua gracilis* is relatively unimportant, except where grazing has been long continued or severe, and is best considered as marking the change toward the disclimax (8). Protected or lightly grazed areas contained only occasional clumps of grama, while the pastures heavily grazed were dominated by it. The tendency of grama to become more abundant the longer the abandonment and consequent grazing is shown from the data of fields 19a and 20a since there are four or five mid-grasses to the one short-grass. During this stage *Calamovilfa longifolia* forms a consociation on sandy soil.

A fourth stage is dominated by the perennial climax grasses to form the *Stipa-Agropyron* climax or faciation which no doubt occurs on fields abandoned from 8 to 12 or more years. This is especially true in terms of composition and to some extent of density. The climax species comprising this stage are *Stipa comata*, *S. viridula*, *Agropyron smithii*, *A. spicatum*, and *Koeleria cristata*.

Although these stages can be distinguished, there is an overlapping in the years of abandonment for each stage considered. The length of time required for the more desirable grasses fully to reclaim

abandoned fields varies on the average from 8 to 12 or more years. This time is dependent on many factors. Length of cultivation plays an important part in the rapidity of re-grassing. Fields cultivated for a year or two and then abandoned revert to the original cover much more rapidly than those tilled more intensively, or for a longer period of time. This indicates that rhizomes and crowns persist over several years of cultivation as was found in Kimball County, Nebraska.[5] The rate is not quite so rapid in Teton County, owing, in part at least, to lower rainfall.

Abandoned areas enclosed with or adjacent to virgin prairie pastures recovered more rapidly than those not so situated for the prairie areas constitute a source of seed, carried in by wind, water, or cattle. In cases of this kind moderate grazing seems to assist or hasten recovery, while close grazing has the opposite effect.

Erosion greatly hinders natural succession and under severe conditions may delay the final recovery many years or entirely prevent it from taking place. Size of abandoned field, whether cropped to non-intertilled or intertilled crops, also affects the rate of recovery. A long narrow abandoned strip recovers more rapidly than the same acreage in more the form of a square, providing there are seed grasses along one entire side.

One of the outstanding features regarding the vegetation of this section of the Great Plains was the fewer species of plants as compared to the larger number found in the central or southern parts. This seemed to be true in the early as well as the later stages of succession.

It seems that the maximum time necessary for complete recovery is shorter in this area than in some of the other sections studied. In Kimball County, Nebraska, this time was estimated to be from 10 to 30 or more years, while it is generally conceded that from 20 to 40 years are required in the Central and Southern Great Plains regions.

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PLACEMENT OF DOLOMITE, SUPERPHOSPHATE, AND BASIC SLAG FOR SOYBEANS, AUSTRIAN WINTER PEAS, AND VETCH[1]

W. B. ANDREWS[2]

THE importance of calcium and phosphorus for nitrogen fixation and the growth of legumes is generally recognized. The comparative value of small amounts of limestone in the drill and large amounts broadcast has been investigated (1, 2, 3, 4, 5, 6, 7).[3] Small amounts of limestone in the drill with the seed often produce excellent increases in the yield and in the nitrogen fixed by legumes. However, Klingebiel and Brown (5) found that fixation of nitrogen was considerably better where the larger quantities were broadcast. They also found that applying lime in the row with the seed produced larger yields of alfalfa containing a higher nitrogen content than applying the same quantity of lime on each side of the seed at a distance of half an inch from the seed.

The purpose of this paper is to report data on the placement of small amounts of dolomite, superphosphate, basic slag, and muriate of potash in the drill relative to soybean, Austrian winter pea, and vetch seed.

EXPERIMENTAL

The test on placement of dolomite, superphoshate, and muriate of potash for soybeans was conducted on Lufkin clay soil of pH 4.65, and for Austrian winter peas on Myatt fine sandy loam of pH 4.5. The placement of basic slag test for vetch was conducted on Myatt fine sandy loam of pH 4.5. The plots were 1/400 acre in size. Each plot was a single row 3.5 feet in width. The seed were sown by hand in a single drill. They were covered approximately 2 inches deep. The soybean seed were planted approximately 2 inches apart. The variety of soybeans was Biloxi. The vetch and Austrian winter peas were sown at the rate of 30 and 40 pounds per acre, respectively.

The dolomite and superphosphate were applied at the rate of 200 pounds of each, and basic slag at the rate of 400 pounds per acre. Muriate of potash was applied at the rate of 0, 50, 100, and 200 pounds per acre. The fertilizers were applied in turning plow furrows made at different depths and distances from the seed, as indicated in the respective tables. There were six replications of each treatment. The data are reported in Tables 1, 2, and 3. All seed were inoculated unless otherwise indicated.

RESULTS AND DISCUSSION

EFFECT OF PLACEMENT OF DOLOMITE, SUPERPHOSPHATE, AND MURIATE OF POTASH RELATIVE TO SOYBEAN SEED ON YIELD OF SOYBEANS

Where superphosphate was placed in contact with the seed and the

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[3]Figures in parenthesis refer to "Literature Cited", p. 341.

dolomite placed 4 inches to one side and 2 inches below the seed, the yield was 4,033 pounds per acre (Table 1). Even though the difference between the latter and the contact placement which produced 3,760 pounds per acre is not statistically significant, a difference of 564 pounds being required for significance, it indicates that the separation of the superphosphate and the dolomite probably had a beneficial effect. The beneficial effect in this case would be due to chemical reactions between the dolomite and superphosphate which would re-

TABLE 1.—*The effect of placement of dolomite and superphosphate relative to the seed on the yield and nitrogen content of soybean hay.*

Plot No.	Placement of 200 lbs. dolomite and 200 lbs. superphosphate per acre relative to seed	Yield of air-dry hay, lbs. per acre	Percentage of nitrogen
1	1 in. below	3,777	1.50±0.085*
2	3 in. below	3,684	1.74±0.094
3	2 in below 2 in. side	4,271	1.85±0.101
4	2 in. below 3 in. side	4,203	1.73±0.108
5	2 in. below 4 in. side	3,997	1.64±0.105
x	Check; not inoculated	3,111	1.51±0.156
6	1 in. below 2 in. side	3,816	1.75±0.092
7	3 in. below 2 in. side	3,843	1.73±0.133
8	Mixed with soil 3 in. below	3,889	1.67±0.065
9	Contact	3,760	1.67±0.082
10	Contact plus 50 lbs. muriate	2,936	1.59±0.115
y	Check; inoculated	3,133	1.55±0.012
11	Contact plus 100 lbs. muriate	2,867	1.42±0.109
12	Contact plus 200 lbs. muriate	1,909	1.17±0.049
13	Super contact, dolomite 4 in. side 2 in. below	4,033	1.47±0.079
14	Dolomite contact, super 4 in. side 2 in. below	4,447	1.83±0.100
15	Dolomite 4 in. side 2 in. below, super 4 in. side 2 in. below	3,817	1.83±0.012
	Standard error	196	
	Standard error of difference	277	
	Difference for significance	554	

*Standard error.

duce the availability of the phosphorus. The beneficial effect of separating the dolomite and superphosphate is further borne out in the placement of the dolomite in contact and the superphosphate 4 inches to one side and 2 inches below the seed which produced 4,447 pounds per acre. The latter yield is significantly greater than that obtained with the contact placement of both dolomite and superphosphate and most of the other placements. Separating the dolomite and superphosphate in the latter case probably had two beneficial effects, *viz.*, (a) increasing the availability of the phosphorus and (b) making the environment more suitable for the soybean nodule bacteria where the dolomite was placed in contact with inoculated seed. Placing the dolomite and superphosphate 2 inches below the seed and 2 inches and 3 inches on one side produced 4,271 and 4,203 pounds per acre, respectively.

The harmful effect of placing muriate of potash in contact with the seed is brought out by the fact that the yield obtained where the

dolomite and superphosphate were applied in contact with the seed was 3,760 pounds per acre, and where 50, 100, and 200 pounds of muriate of potash were added to the dolomite and superphosphate in contact with the seed, the yields were reduced to 2,936, 2,867, and 1,909 pounds per acre, respectively. Muriate of potash reduced the stand and caused the soybeans to have a lighter green color.

EFFECT OF PLACEMENT OF DOLOMITE, MURIATE OF POTASH, AND SUPERPHOSPHATE RELATIVE TO SOYBEANS SEED ON NITROGEN CONTENT OF SOYBEANS

The nitrogen content of the soybeans receiving no fertilizer treatment was $1.55 \pm 0.012\%$. Placing the dolomite and superphosphate 2 inches below and 2 inches to one side of the seed increased the nitrogen content to $1.85 \pm 0.101\%$. The nitrogen content was $1.83 \pm 0.100\%$ where the dolomite was placed in contact and the superphosphate was placed 4 inches on one side of the seed and 2 inches below and $1.83 \pm 0.012\%$ where the dolomite and superphosphate were placed on opposite sides of the seed 4 inches away and 2 inches below. The addition of 200 pounds of muriate of potash to the contact placement of dolomite and superphosphate reduced the nitrogen content to $1.17 \pm 0.049\%$. The other increases in nitrogen content are not statistically significant. The fertilizer placements which produced high increases in yield also produced significant increases in nitrogen content.

EFFECT OF PLACEMENT OF DOLOMITE, SUPERPHOSPHATE, AND MURIATE OF POTASH RELATIVE TO AUSTRIAN WINTER PEA SEED ON YIELD

The yield obtained with dolomite and superphosphate together 2 inches below and 2 inches to the side of the seed was 1,767 pounds of dry peas (Table 2), superphosphate in contact and dolomite 2 inches below and 2 inches to the side produced 1,052 pounds, superphosphate on one side and dolomite on the other 2,084 pounds, and dolomite in contact and superphosphate to the side 2,189. The difference required for significance was 415 pounds per acre. When superphosphate was placed in contact with the seed, dolomite was no more effective in the contact than in the side placement. As was the case with soybeans, there is apparently a real increase in yield due to the separation of dolomite and superphosphate. The beneficial effect is apparently both chemical and biological.

With the mixture of superphosphate and dolomite placed 2 inches below the seed, the yield was 1,767, 1,943, and 1,398 pounds of air-dry peas per acre at 2, 3, and 4 inches to the side of the seed, respectively. When the mixture of dolomite and superphosphate was placed 2 inches to the side of the seed, the depth of placement of 1, 2, and 3 inches had no significant effect on the yield. Muriate of potash in contact with the seed reduced the yield very significantly when as little as 50 pounds of muriate of potash was applied.

Placing dolomite in contact with the seed probably and a beneficial effect on the inoculation. Inoculation alone increased the yield with-

TABLE 2.—*The effect of fertilizer placement on the yield of Austrian winter peas.*

Plot No.	Placement of 200 lbs. superphosphate and 200 lbs. dolomite per acre relative to seed	Yield of air-dry Austrian winter peas, lbs. per acre
1	1 in. below	1,440
2	3 in. below	1,244
3	2 in. below 2 in. side	1,767
4	2 in. below 3 in side	1,943
5	2 in. below 4 in. side	1,398
x	No fertilizer	674
6	1 in. below 2 in. side	1,807
7	3 in. below 2 in. side	1,802
8	Mixed with soil to a depth of 3 in. below	1,471
9	Contact	1,089
10	Contact plus 50 lbs. muriate	745
11	Contact plus 100 lbs. muriate	644
12	Contact plus 200 lbs. muriate	475
x	No fertilizer or inoculation	76
13	Super contact, dolomite 2 in. below, 2 in. side	1,052
14	Dolomite contact, super 2 in. side, 2 in. below	2,189
15	Super one side, dolomite other side, 2 in. side, 2 in. below	2,084
	Standard error	147
	Standard error of difference	207
	Difference for significance	415

out fertilizer from 76 to 674 pounds of air-dry peas per acre. There was no indication that placement of the fertilizers affected the nitrogent content of Austrian winter peas.

EFFECT OF PLACEMENT OF BASIC SLAG RELATIVE TO THE SEED ON YIELD OF VETCH

The yield of air-dry vetch (Table 3) without fertilizer treatment was 1,100 pounds per acre. Placing the basic slag in contact with, 1 inch below, and 3 inches below the seed increased the yield to 2,264, 2,108, and 2,153 pounds of air-dry vetch per acre, respectively. These treatments were all good and there was apparently no difference

TABLE 3.—*The effect of placement of basic slag relative to the seed on the yield of vetch.*

Plot No.	Placement of 200 lbs. of basic slag per acre	Yield of air-dry vetch, lbs. per acre
1	No basic slag	1,100
2	Contact with seed	2,264
3	1 in. below seed	2,108
4	3 in. below seed	2,153
5	1 in. to side of seed, 1 in. below	1,848
6	2 in. to side of seed, 1 in. below	1,940
7	3 in. to side of seed, 1 in. below	1,617
8	4 in. to side of seed, 1 in. below	1,645
	Standard error	172
	Standard error of difference	243
	Difference for significance	486

between them. The yields were 2,108, 1,848, 1,940, 1,617, and 1,645 pounds of air-dry vetch per acre where the basic slag was placed 1 inch below and 0, 1, 2, 3, and 4 inches to the side, respectively. The side placements were all inferior to the contact or below placements.

SUMMARY AND CONCLUSIONS

A fertilizer placement test was conducted with soybeans and Austrian winter peas. The fertilizers used were dolomite, superphosphate, and muriate of potash. A basic slag placement test with vetch was also conducted. The data may be summarized as follows:

1. Placing the mixture of dolomite and superphosphate 2 inches to one side and 2 to 3 inches below the seed was superior to contact placement.
2. Muriate of potash in contact with the seed decreased the yield.
3. The best placement was dolomite in contact and superphosphate below and to the side of the seed. The data indicate that the separation of dolomite and superphosphate prevented undesirable chemical reactions and stimulated the nodule bacteria.
4. In general, the fertilizer placement producing the highest yield of soybeans produced the highest nitrogen content, but placement had no effect on the nitrogen content of Austrian winter peas.
5. Placing basic slag in contact with or below vetch seed was superior to side placements.

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INHERITANCE AND LINKAGE RELATIONSHIPS OF A CHLOROPHYLL MUTATION IN RICE[1]

N. E. JODON[2]

A VIRESCENT white-stripe chlorophyll deficiency in rice plants was found in 1933 in a heterozygous condition in an F_4 selection from a Kameji×Blue Rose cross. The emerging seedlings were nearly white with indefinitely bordered linear areas of chlorophyll. New leaves and emerging panicles also were deficient in chlorophyll. Counts made on segregating progeny in subsequent generations indicated that the inheritance of the virescent character was determined by a single recessive factor. It was noted also that the rate of development of chlorophyll varied from season to season, and that virescent plants tended to be smaller than normal plants.

The present paper reports the mode of inheritance and linkage relations of five character pairs in rice, *viz.*, normal vs. virescent, clustered vs. normal floret arrangement, common vs. glutinous kernels, purple vs. colorless apiculus, and late vs. early maturity, in a cross between C. I.[3] 4630 with strain No. 2912A21 breeding true for virescent seedlings and late maturity.

LITERATURE REVIEW

The literature on rice genetics originates from widely scattered sources and in some instances it is not possible to be certain of the identity of the characters reported by different workers. Jones (4)[4] summarized published data on F_2 ratios. Single-factor ratios were reported for green×white stripe and common× glutinous endosperm. Earliness and lateness were each reported as single factor dominants. Purple color in the apiculus was controlled by two or more factors. Ramiah, *et al* (9) reported clustering as a single-factor dominant. The F_1 was intermediate, and a 1:2:1 ratio was obtained in the F_2. Ramiah and Ramanujam (10) found and illustrated a green-and-white-stripe single-factor recessive mutant, which probably was identical with the one reported here. Ramiah (8) obtained a trimodal curve for maturity in one cross from which the earlier and later strains bred true. In other crosses multiple factors were involved and reversal of dominance occurred in certain segregating selections. Jones, *et al.* (5) found 3 late : 1 early, 9 late : 7 early, and multiple-factor ratios.

Linkage between apiculus color and endosperm type was first reported by Yamaguchi, according to Matsuura (7). Yamaguchi also found a maturity factor in this linkage group, the order being apiculus—endosperm—maturity. Chao (1) assigned a factor for tawny glume color and one for leaf sheath color to this linakage group.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Louisiana Agricultural Experiment Station. Work conducted at Rice Experiment Station, Crowley, La. Paper also presented at the annual meeting of the American Society of Agronomy at New Orleans, La., November 24, 1939. Received for publication February 20, 1940.

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[3]C. I. refers to accession numbers of the Division of Cereal Crops and Diseases.

[4]Numbers in parenthesis refer to "Literature Cited", p. 346.

MATERIALS AND METHODS

In 1936 a cross was made between strain No. 2912A21 and C. I. 4630 after emasculation by the hot-water method (3). C. I. 4630 has a clustered arrangement of the florets on the panicle branches, deep purple apiculus, glutinous endosperm corresponding to waxy in maize, matures early, and produces normal green seedlings. Strain No. 2912A21 bred true for virescent seedlings, normal arrangement of florets on the panicle branches, common starch development, colorless apiculus, and late maturity. The F_1 seeds were germinated indoors and the seedlings were transplanted to the field after reaching a height of 4 or 5 inches. F_1 endosperms were common or non-glutinous. F_1 plants grown in 1937 were late in maturity, had normal chlorophyll, clustered florets, and purple apiculi. The F_2 data were obtained in 1938. Emergence of the F_2 plants was rather irregular due to unfavorable moisture conditions and cool weather, but the stand was satisfactory.

Virescent seedlings were staked as noted, but it was found that this character was classified more satisfactorily by the whiteness of the emerging panicle. Virescent and date of panicle emergence were recorded at 2- to 5-day intervals on tags which were attached to the panicles with paper clips. A single mature panicle was harvested from each of the 890 F_2 plants and classification of the three remaining characters was made in the laboratory. All plants having any tendency for the florets to be clustered were included in the "cluster" class without attempting to separate the fully clustered from the intermediates. Since rice is normally self fertilized, those segregating for endosperm character were classed as common. The purple apiculus was distinct and easily separated from the nonpurple.

EXPERIMENTAL RESULTS

Data in Table 1 show that the F_2 segregation for each of the five character pairs studied was in satisfactory agreement with a 3 : 1 ratio. A 3 : 1 ratio had been previously reported for red but not for purple vs. colorless apiculus. A few of the virescent segregates appeared to contain less chlorophyll than the parent strain, the panicles remaining white when nearly mature.

The assumption of a single basic or major factor for maturity with lateness dominant seems justified by the apparently bimodal form of the distribution of panicle emergence dates in F_2 as shown in Fig. 1.

The curve, based on 7-day periods, is somewhat irregular for the early group, but rapidly rises to a peak and declines rather abruptly for the late group. The effect of weather conditions must be considered in connection with irregularities in heading in rice. Heading is retarded by cool, cloudy, and rainy weather, whereas it is hastened by warm, clear, calm weather.

There was marked transgressive segregation for maturity as indicated by panicle emergence ranging from 22 days earlier than the early parent (C. I. 4630) to 39 days later than the late parent, a total range of 96 days. All plants heading before the late parent, i.e., up to August 22, were grouped as early. This covered approximately half the total heading period. At Crowley, La., August 20 is the heading date usually considered as separating early and midseason from late strains. Although the curve (Fig. 1) rises toward the peak for late maturity for the week ending August 22, it is not so high then as at

TABLE 1.—*Segregation for five characters in an F_2 of the cross virescent × C. I. No. 4630, cross No. 4-107a4.*

Character	Number of plants	Chi square, (3:1 ratio)	Probability
Chlorophyll:			
Normal	691		
Virescent	199	3.309	0.10-0.05
Total	890		
Floret arrangement:			
Cluster	673	0.181	0.70-0.50
Normal	217		
Total	890		
Type of starch:			
Common	673	0.181	0.70-0.50
Glutinous	217		
Total	890		
Apiculus color:			
Purple	665		
Colorless	225	0.037	0.90-0.80
Total	890		
Maturity:			
Late	678		
Early (Aug. 20 or earlier)	212	0.661	0.50-0.30
Total	890		

the peaks for early maturity. When all plants heading after August 12 were considered as late maturing, a deficiency in the early class was obtained. For the purpose of studying linkage relationships, however, lateness is considered here as a single factor dominant.

The Chi-square test for independence was used to detect association among the characters studied. All characters were found to be associated except floret arrangement and endosperm type. The recombination percentages calculated by the product method and with the aid of Immer's tables (2) are given in Table 2.

Fig. 2 shows the same data in the form of a chromosome map. The symbols used in Table 2 and Fig. 2 are those proposed by Kadam and Ramiah (6). The four qualitative factors are arranged as follows: *gu-as-v-cl*. The smallest linkage value obtained (7.5%) was that between *v* and *fl*, but the relative position of these two genes could not be determined because of conflicting data. Since the recombination percentage is 24.5 between *as* and *v*, 30.0 between *as* and *fl*, and 7.5 between *v* and *fl*, the indicated order is *as-v-fl*. Since the recombination percentage is 42.5 between *cl-as*, 34.5 between *cl-v*, and 40.5 between *cl-fl*, the indicated order is *as-fl-v-cl*.

It should be noted that Yamaguchi (7) reported that the arrangement of the factors he placed in this linkage group was *fl-gu-as*. Either different factors are involved from those in Yamaguchi's

TABLE 2.—*Percentage of recombinations among five characters in the cross virescent × C. I. 4630, cross No. 4-107a4.*

Characters	Chlorophyll	Floret arrangement	Endosperm type	Apiculus color	Maturity
Chlorophyll (v)	—	34.5	40.5	24.5	7.5
Floret arrangement (cl)	—	—	—*	42.5	40.5
Endosperm type (gu)	—	—	—	22.5	41.0
Apiculus color (as)	—	—	—	—	30.0
Maturity (fl)	—	—	—	—	—

*Independent Chi square = 2 067 P = 0 20–0.10

material or lateness in the cross reported here cannot be ascribed to a major single dominant factor. It is possible that the three recombi-

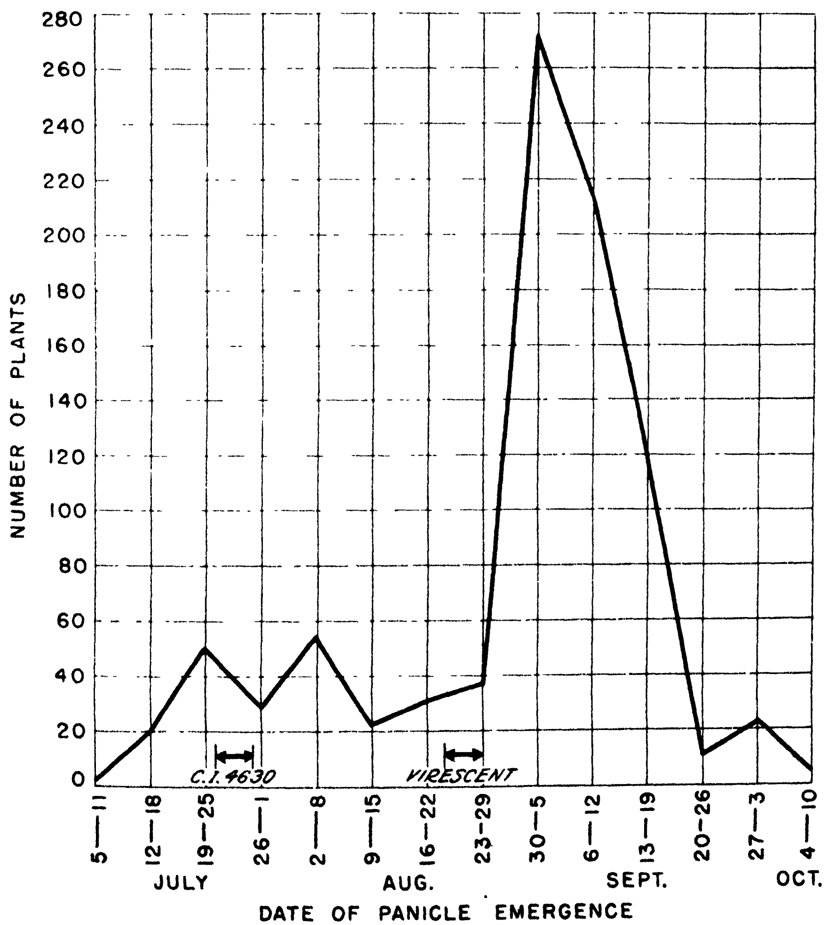

FIG. 1.—Distribution of dates of panicle emergence in F_2 of cross No. 4–107a4.

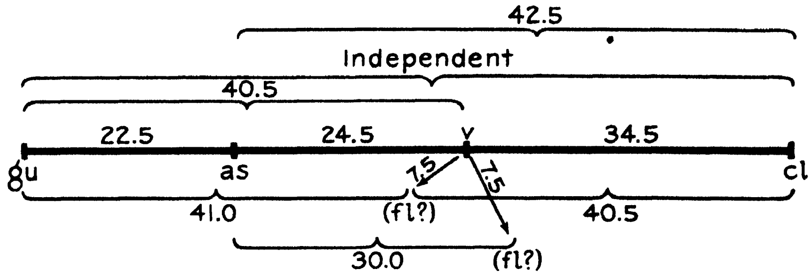

FIG. 2.—Linkage map, showing relative position of factors studied in cross No. 4-107a4 and their recombination percentages.

nation percentages, 40.5, 41.0, and 30.0, are approximations of 50% and that the *fl* 7.5% represents some physiological relationship of virescent with maturity. In another cross, however, the writer obtained linkage values of 30 and 37% between *as* and *fl*. The linkage value of 22.5% between *gu* and *as* agrees closely with the 20 to 22% obtained by Yamaguchi and Takahashi as reported by Matsuura (7), and the 22.34% obtained by Chao (1).

SUMMARY

A recessive virescent mutation (*v*) appeared in an F_4 Kameji × Blue Rose progeny row. In the F_2 generation of a cross No. 2912A21 (virescent) × C. I. 4630 (normal), virescence was found to be linked with three other recessive factors in the following order: *Glutinous-colorless apiculus-virescent-noncluster*. A maturity factor was apparently closely linked with virescent, but the relative position was not determined.

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EFFECT OF THE METHOD OF COMBINING THE FOUR INBRED LINES OF A DOUBLE CROSS OF MAIZE UPON THE YIELD AND VARIABILITY OF THE RESULTING HYBRID[1]

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LARGE scale production of inbred lines from several varieties of corn was begun at the Iowa Agricultural Experiment Station in 1922. Hundreds of lines were started, the majority of which have been discarded, but a number of good ones have been produced from each of the varieties. The task remains of combining the best of them to produce the most desirable hybrid combinations. Even with relatively few lines, making and testing of all possible hybrid combinations is a staggering task. Thus with only 40 inbreds, 780 single crosses and 274,170 double crosses are possible.

This paper reports the effect upon the yield and variability of two methods of making double crosses among lines from different varieties.

REVIEW OF LITERATURE

Jenkins (3)[3] was the first to use the performance records of single and inbred-variety crosses in predicting the performance of double crosses. He used four different methods as follows (a) the mean values of all possible single crosses among the four lines, (b) the mean value of the four single crosses not used as parents, (c) the mean of all single-cross tests involving each one of the four parent lines, and (d) the mean of the inbred-variety crosses of the four lines. The methods involving single-cross combinations were found to be most reliable. The most important advantage of the inbred-variety cross method was that it permitted the inclusion of all the inbred lines in the tests each year.

Doxtator and Johnson (2) used Jenkins' method (b) in which the four single crosses not used as parents in the double cross were averaged to predict the character desired. They were able to predict the relative yields of double crosses very closely.

Anderson (1) also concluded that double cross yields could be predicted closely by averaging the yield of the four single crosses not used as parents of the double cross.

Wu (6) compared single cross yields in which the inbred parents were derived (a) from the same single cross, (b) from single crosses having one line in common, and (c) from unrelated single crosses. Crosses of closely related material (a) were significantly lower in yield than those from (b) and (c). Crosses of the inbreds from (b) were not significantly different in yield than crosses among inbreds from (c), the unrelated inbreds.

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[3]Figures in parenthesis refer to "Literature Cited", p. 353.

MATERIAL AND METHODS

Four inbred lines from each of three varieties were used. They were as follows: I 159, I 205, I 224, and I 233 from Iodent; L 289, L 317, L 324, and L 326 from Lancaster Surecrop; and Bl 339, Bl 345, Bl 349, and Bl 351 from Black Yellow Dent. Black Yellow Dent and Iodent are selections from Reid Yellow Dent, but Lancaster Surecrop is a Pennsylvania variety, distantly if at all related to the other two varieties.

Two methods were used in making the double crosses. Designating inbreds from one variety as A and B and inbreds from a second variety as Y and Z, double crosses were made as follows: (A×B)×(Y×Z) and (A×Y)×(B×Z). Paired double crosses produced in this manner were compared to determine the better method of combining the inbreds. Only one of the double crosses (A×Y)×(B×Z) or (A×Z)×(B×Y) was used, the particular combination chosen depending on available seed.

Double crosses composed of four inbred lines from the same variety were included to compare with those hybrids composed of inbreds from two varieties. Two open-pollinated varieties and two commercial hybrids were included as standards of comparison.

The field plots in 1936 and 1937 were arranged in randomized blocks. In 1938 the pair (A×B)×(Y×Z) and (A×Y)×(B×Z) was treated as a unit in the randomization process and then the hybrids within the pair were randomized. The plots were two by ten hills and each entry was replicated six times Acre yields each year were computed on the basis of shelled grain containing 15% moisture.

Data were taken in 1936 on ear height and in 1937 on ear height, plant height, ear weight, ear length, and ear diameter in the following manner: In each hill of the plots (2×10 hills) in the replications sampled, one stalk was chosen at random and tagged. In the fall, plant and ear heights on these 20 plants per plot were determined and the ears dried and weighed individually. Ear length and ear diameter were recorded at the time of weighing. Ear diameters were taken about one-sixth of the distance from the butt to the tip. In 1936 three replications (60 plants) and in 1937 five replications (100 plants) were sampled for the studies. From these data the variance within strains was computed for each character.

EXPERIMENTAL RESULTS

In 1936, double crosses of the formula (A×B)×(Y×Z) outyielded their comparable (A×Y)×(B×Z) double crosses by an average of 3.08 bushels. In only 2 of the 12 pairs did double crosses of the formula (A×Y)×(B×Z) yield more than the double crosses of formula (A×B)×(Y×Z). In these cases the inbred lines were from Black Yellow Dent and Iodent, both selections of Reid Yellow Dent. A significant difference in favor of the (A×B)×(Y×Z) double crosses was shown by an X^2 test.

In 1937, the mean yields for the (A×B)×(Y×Z) double crosses exceeded the yield of their comparable (A×Y)×(B×Z) double crosses by 3.72 bushels, but the absolute yields were much higher in 1937 than in 1936. When three pairs were omitted from the calculations because of poor stands for at least one of the pair, the mean difference between the combinations produced by the two methods was not significant. Notwithstanding this general relationship, the

highest yielding hybrid, Iowa Hybrid 3110 (I 159×I 224)×(L 289×L 317) was 18.2 bushels above its comparable hybrid, Iowa Hybrid 3490 (I 159×L 289)×(I 224×L 317).

In 1938, another excellent year for maize, the yield differences between hybrids combined (A×B)×(Y×Z) vs. (A×Y)×(B×Z) were highly significant and in favor of the first arrangement. As these were paired in the field plot arrangement in the 1938 test, the 1938 data afford the more accurate test of hybrid comparisons between members of a pair.

Table 1 gives the yields of the hybrids for the 3-year period 1936, 1937, and 1938. The analysis of variance, shown in Table 2, reveals that the variance between the methods of combining the lines was highly significant. Years account for most of the total variation and this variance likewise is highly significant. Differences between pairs were highly significant as was the interaction pairs×years. Drouth conditions in 1936 and favorable conditions in 1937 and 1938 resulted in yields of maize which differed greatly. This accounts for the great variation between years. The variance ascribed to the interaction of pairs×years is highly significant because of the failure of the pairs to keep the same relative rank throughout the 3-year period. The significance of pairs by years interaction confirms other yield test results in which Iowa Hybrid 13 has done relatively better in drouth seasons while Iowa Hybrid 3110 has done relatively better in favorable maize seasons.

The F values for ear height in 1936 and those on ear height, plant height, ear weight, ear length, and ear diameter in 1937 are shown in Table 3. They were computed by dividing the "within" sum of squares for double crosses of the formula (A×Y)×(B×Z) by the similar sum of squares for the (A×B)×(Y×Z) double crosses.

In 1936, the variance for ear heights for the (A×B)×(Y×Z) group was not significantly lower than the variance for the (A×Y)×(B×Z) group, but in 1937 the lower variance of the (A×B)×(Y×Z) group was highly significant. No significant difference was found between the two groups in plant height, ear weight, or ear diameter, but a highly significant difference was found in ear length, with the (A×B)×(Y×Z) double crosses having the lower variance.

DISCUSSION

A variety of maize is composed of many different genotypes. Taken together, the plants of any variety have a certain gene frequency for their characters. The sum total of the gene frequencies for all characters distinguish and characterize the variety. Black Yellow Dent, Osterland Yellow Dent, and Iodent were selected from Reid Yellow Dent and through the selection process, the gene frequencies affecting the development of many characters were changed. Other gene frequencies were little affected by the selection process. Varieties such as Lancaster Surecrop have gene frequencies differing markedly from the varieties selected from Reid Yellow Dent.

Jenkins (4, 5) has shown that inbred lines achieve stability, so far as the average yield of their hybrid progeny is concerned, rather early

TABLE 1.—*Acre yields of double crosses for the three-year period, 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Acre yield in bushels in the year indicated			
		1936	1937	1938	Av.
	Black Yellow Dent	20.7	75.5	90.1	62.1
	Krug	25.3	60.5	88.6	58.1
Iowa Hybrid 939	(I205×L289)×(Os420×Os426)	31.2	94.6	101.9	75.9
Iowa Hybrid 13	(L317×Bl349)×(Bl345×Mc401)	44.9	87.1	117.8	83.3
3474	(I 159×I 224)×(I 205×I 233)	31.9	73.9	101.3	69.0
3482	(I 159×I 233)×(I 205×I 224)	25.7	65.1	104.1	65.0
3628	(L 289×L 317)×(L 324×L 326)	28.1	90.1	93.8	70.7
3641	(L 289×L 324)×(L 317×L 326)	33.6	93.5	102.1	76.4
3669	(Bl 339×Bl 345)×(Bl 349×Bl 351)	32.4	81.1	97.7	70.4
3670	(Bl 339×Bl 349)×(Bl 345×Bl 351)	29.5	85.1	101.1	71.9
3110	(I 159×I 224)×(L 289×L 317)	36.9	111.1	117.3	88.4)
3490	(I 159×L 289)×(I 224×L 317)	29.1	92.9	106.5	76.2)‡
3477*	(I 159×I 224)×(L 324×L 326)	32.9	85.4	107.3	75.2)
3492*	(I 159×L 324)×(I 224×L 326)	29.7	86.8	99.8	72.1)‡
3535	(I 205×I 233)×(L 289×L 317)	30.9	88.2	109.1	76.1)
3558	(I 205×L 289)×(I 233×L 317)	27.4	90.7	105.6	74.6)‡
3537*	(I 205×I 233)×(L 324×L 326)	38.7	94.6	106.8	80.0)
3561*	(I 205×L 324)×(I 233×L 326)	35.4	64.8	102.5	67.6)‡
3478	(I 159×I 224)×(Bl 339×Bl 345)	30.2	85.7	106.0	74.0)
3493	(I 159×Bl 339)×(I 224×Bl 345)	30.9	90.6	108.7	76.7)
3111*	(I 159×I 224)×(Bl 349×Bl 351)	34.3	91.0	49.9	62.6)†
3495*	(I 159×Bl 349)×(I 224×Bl 351)	32.7	86.7	109.9	59.7)†‡
3538	(I 205×I 233)×(Bl 339×Bl 345)	30.5	86.2	113.7	76.8)
3562	(I 205×Bl 339)×(I 233×Bl 345)	34.5	77.1	105.9	72.5)‡
3540*	(I 205×I 233)×(Bl 349×Bl 351)	36.7	91.2	105.7	77.9)
3565*	(I 205×Bl 349)×(I 233×Bl 351)	33.9	78.4	100.5	70.9)‡
3629	(L 289×L 317)×(Bl 339×Bl 345)	33.3	87.0	104.7	75.0)
3716	(L 289×Bl 339)×(L 317×Bl 345)	27.1	89.0	100.4	72.2)‡
3114	(L 289×L 317)×(Bl 349×Bl 351)	40.5	98.7	114.0	84.4)
3643	(L 289×Bl 349)×(L 317×Bl 351)	36.5	97.0	103.7	79.1)‡
3666	(L 324×L 326)×(Bl 339×Bl 345)	35.4	94.9	94.6	75.0)
3717	(L 324×Bl 339)×(L 326×Bl 345)	27.7	84.0	93.5	68.4)‡
3667	(L 324×L 326)×(Bl 349×Bl 351)	43.3	93.9	101.6	79.6)
3668	(L 324×Bl 349)×(L 326×Bl 351)	41.7	95.2	96.0	77.6)‡
	Average	33.9	90.1	105.0	

*Not used in the analysis of variance because of poor stand.
†Two-year average
‡Higher yield for (A×B)×(Y×Z) double cross.

in the inbreeding process. Presumably this is because equal numbers of dominant genes will be preserved by chance through successive generations of inbreeding due to the probability that the modal classes will be represented by the sample selected. Similarly, it might be expected that many of the inbred lines from a single variety would have many favorable growth genes in common. If a variety has many genes favorable for a given trait, the probability is high that most of the inbred lines derived from this variety will receive favorable genes

for this trait. Inbred lines from another variety, especially one that is distantly related, would presumably differ genetically from those of the first variety to a greater extent than they would from each other.

TABLE 2.—*Analysis of variance of the data on acre yield presented in Table 1.*

Source of variation	D/F	Net sum of squares	Mean square	F value
Method of combining	1	192.00	192.00	16.30**
Pairs	7	619.02	88.43	7.51**
Years	2	46,207.87	23,103.93	1,961.28**
Methods×pairs	7	201.49	28.78	2.44
Methods×years	2	7.39	3.69	0.31
Pairs×years	14	779.08	55.65	4.72**
Methods×pairs×years	14	164.99	11.78	———
Total	47	48,171.84		

**Highly significant (1% level)

TABLE 3.—*F values for the characters studied.**

Year	Ear height	Plant height	Ear weight	Ear length	Ear diameter
1936	1.03	——	——	——	——
1937	1.25**	1.06	1.03	1.12†	1.07

*An F value greater than 1.00 indicates less variation in the (A×B)×(Y×Z) double cross
†Significant (5% level)
**Highly significant (1% level).

Since, as Jenkins has stated (3), "In any double cross, the genes of each of the four parental lines are united only with the allelemorphs of the two lines which entered the double cross from the opposite parent," the highest yielding double cross involving any four inbred lines should be the one which utilizes the two lowest yielding single crosses among the four lines as its parents. The two inbred lines from the same variety would presumably be somewhat alike genetically and therefore would perform best when entering the double cross from the same side of the parentage. On the average, inbred lines from different varieties would presumably have more favorable growth genes which are not common to each other and should perform best when entering the double cross from opposite parents.

The double crosses of formula (A×B)×(Y×Z) out-yielded their comparable double crosses 11 times out of 12 in a 3-year average (Table 1). The difference was highly significant. In only one pair, Iowa Hybrid 3478 (I 159×I 224)×(Bl 339×Bl 345) vs. Iowa Hybrid 3493 (I 159×Bl 339)×(I 224×Bl 345), did the hybrid combining inbreds from two varieties into the single crosses yield more than by combining inbreds from the same varieties into the parent single crosses. This exception was consistent for the 3 years during which the experiment was conducted and is explicable because Iodent and Black Yellow Dent both were selections from Reid Yellow Dent and would have many genes in common.

Not only did the (A×B)×(Y×Z) double crosses usually outyield the (A×Y)×(B×Z) double crosses, but the highest yielding double

crosses were those which combined one single cross of Lancaster inbreds with a single cross of Black Yellow Dent or Iodent inbred lines. The greatest hybrid vigor came from crossing single crosses distantly related.

The desirability of combining inbred lines from the same variety into the single-cross parents of double crosses is confirmed by experiments of Doxtator and Johnson (2) and Anderson (1). Doxtator and Johnson concluded the combination (11×14)×(374×375) had been selected as the most desirable double cross at the Waseca station. Inbreds 11 and 14 are from the Minnesota 13 variety, while inbreds 374 and 375 are from Reid Yellow Dent. Anderson (1) used two inbred lines from Reid Yellow Dent and three inbred lines from Golden Glow. In every test in which the two inbreds from Reid Yellow Dent were combined with the inbreds from Golden Glow into all possible double cross combinations the highest yield occurred when the two inbred lines from Reid Yellow Dent were combined in one single-cross parent and two inbreds from Golden Glow combined in the other single-cross parent.

With the exception of Iowa Hybrid 3641 (L 289×L 324)×(L 317×L 326), every pair of hybrids containing inbreds from two varieties had at least one member which had a higher yield than those hybrids from inbreds out of the same variety. The lower yield of the hybrids from inbreds all from the same variety is probably due to close relationship.

The degree of relationship among the parental lines also can be attacked by measuring the relative variability of the two kinds of double crosses. If the double cross (A×B)×(Y×Z) is significantly less variable for a particular character than the double cross (A×Y)×(B×Z), it can be reasoned that the two parental single crosses (A×B) and (Y×Z) each involved inbreds carrying many genes in common for the trait measured, or at least carrying more genes in common than would be the case of A vs. Y and B vs. Z.

Ear height variance as determined in 1936 showed no significant difference between methods of combining inbred lines, but in 1937 the lower variance for the (A×B)×(Y×Z) crosses was highly significant. The crop season of 1937 was much more favorable for maize production than was the drouth year 1936.

The differences in variance for ear weight and ear diameter between (A×B)×(Y×Z) vs. (A×Y)×(B×Z) double crosses were not significant. Ear length, however, was significantly less variable in the (A×B)×(Y×Z) double cross (Table 3). The Lancaster inbreds as a rule are long and slender, while the Black Yellow Dent and the Iodent inbreds are shorter and thicker.

SUMMARY

In double crosses involving two inbreds from each of two varieties, the combinations which brought together the inbreds of the same variety in the parental single crosses were consistently higher yielding.

The highest yielding double crosses were those that combined single crosses of widely different parentage.

Significantly lower variances for ear height and ear length resulted from combining two inbreds from the same variety in each single cross parent. Lower variances were also found for plant height and ear weight, although in the case of these two characters the differences associated with method of combining were not statistically significant.

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RELATION OF BORON TO HEART ROT IN THE SUGAR BEET[1]

T. R. Cox[2]

A DISEASED condition of sugar beets hitherto not reported for this country was observed by Kotila (22)[3] in Gratiot County, Michigan, in 1932. It was noted in several other counties in 1933 and in Gratiot, Saginaw, Tuscola, Bay, Isabella, Clinton, Huron, and Ingham counties of Michigan and in Henry County, Ohio, in 1934. Subsequent studies by Kotila and Coons (23) showed that the diseased condition was due to a deficiency of boron, and in accord with the reports of European workers the disease was called heart rot.

Recent surveys by other workers (8) have indicated that some of the beet soils of Michigan have a boron content inadequate for the needs of a normal crop unless weather conditions are very favorable. As this deficiency of boron became more generally known, requests were soon received from beet growers for advice on the use of boron, and from fertilizer manufacturers as to the wisdom of preparing special fertilizers containing a low percentage of borax or boric acid. Accordingly, the Soils Section of the Michigan Experiment Station started field experiments in 1936 and greenhouse experiments in the spring of 1937 to test the value of borax as a control for heart rot on Michigan soils and to obtain information relative to the accumulation of boron in soils after repeated applications. Some of the results of these preliminary experiments are reported in this paper.

HISTORICAL

Since most of the literature pertaining to boron deficiency in sugar beets has been published in foreign journals and for that reason is not easily accessible to many interested persons, a rather broad review of the subject is herein attempted.

Studies by Paasch (30) in Germany on the cause and control of heart and dry rot indicate with a high degree of certainty that the disease now recognized as due to boron deficiency was observed in certain sections of Germany as early as 1886. His study of the records of incidence of heart rot of beets in relation to meteorological conditions from 1886–1929, inclusive, shows a marked prevalence in periods of protracted drought between mid-June and mid-September. Esmarch (12) made a corresponding report from Germany in 1928. Gram (18), Meyer-Bahlburg (27), Hauley and Mann (19), Fron (13), and others studying the disease more recently as a boron deficiency are in accord with this early observation that drought is very conducive to the disorder.

[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Authorized for publication by the Director as Journal Article No. 424 (n. s.) of the Michigan Agricultural Experiment Station. Taken from a thesis submitted to the Graduate School of Michigan State College in partial fulfillment of the requirements for the degree of master of science. Received for publication February 24, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 368.

The association of boron deficiency with alkaline conditions seems to follow the investigations of many early workers attempting to trace the disease to some definite cause. Arrhenius (1) reported greater infestations in 1924 with slightly acid or nearly neutral soil conditions in either field or pot experiments. Garbowski (15), in a report for Poland, Pomerania, and Silesia for the season of 1921–22, indicates by the following statement that heart rot was prevalent in his territory: "Cases were also observed of a rot of the youngest leaves in the heart of the crown, correlated with a dry rot of the roots, stated to be due to the accumulation of alkaline salts in the soil; later the diseased tissues may be invaded by parasitic fungi."

Gallegher (14) investigated by extensive survey in 1928 the relation of soil reaction to failures of the beet crop in sections of Ireland and found that areas in which the disease was prevalent occurred on highly alkaline soil. A soil reaction of pH 6.5 appeared to be optimum for the normal development of the sugar beets while a reaction above pH 8.0 was especially conducive to the disorder. It is further pointed out that the maximum pH tolerance is higher in the humid Irish climate than in a drier climate such as Switzerland's where pH 7.0 is the point above which the disease is most severe.

Verhoven (37) of Holland reported a form of heart rot supposedly associated with excess alkalinity and dry weather, and Van Poeteren (36) reported for 1925 that excessive alkalinity of the soil is primarily responsible for a diseased condition similarly described. In 1930, Paasch (30) recommended that, as an aid in controlling heart and dry rot of beets in Breslou, Germany, calcareous fertilizers be avoided for dry alkaline soils.

Rambousek (32) reported a heart rot in Czechoslovakia for 1923 in which *Phoma betae* and other species of organisms apparently played a part. In order to prove whether or not soil conditions were important causal factors, Rambousek attempted to reproduce the same disease by introducing a virile culture of *Phoma betae* into healthy beets. His efforts to produce the disease failed consistently and he naturally concluded that other factors than bacteria contribute to the disease.

There is a striking correlation of symptoms reported from investigations completed prior to discovery of the boron relationship and those carried on afterwards. Rambousek (31) pointed out that the cavities or "growth cracks" under the heart caused by rapid growth should not be confused with the diseased condition, heart rot. Verhoven (37) described his "galloping heart rot" associated with alkalinity and dry weather as affecting the youngest leaves which turn black and die, followed by crown decay. McLarty (26) described with identical symptoms a rot of seed bearing, long red mangel beets. A well-illustrated paper by Kruger and Wimmer (25) in 1927 describes the heart and dry rot disease. They conclude that faulty nutrition or metabolic disturbance is the cause of the disease and that it is not pathogenic as previous workers had believed. They did not, however, indicate any belief or knowledge that boron deficiency was the nutritional factor involved.

The best early description of the disease is given by Gaumann (16, 17) of Switzerland who states that a soil pH of 7.8 gives incidence of the disease too great to allow profitable production of sugar beets. The following points are listed from his observations reported in 1925 because they correspond so perfectly with symptoms induced by boron deficiency a few years later by Brandenburg:

1. Dark discoloration of inner concave side of petioles of medium sized leaves, accompanied by frequent deformation of leaves.

2. Characteristic zonate fissures in concave side of petiole. Heart rot in advanced cases.
3. Development of symptoms without any trace of *P. betae* infection.
4. Based on chronological observations of symptoms, involvement of two distinct pathological processes, (a) primary physiological disturbance and (b) secondary parasitic attack.

A publication by Brandenburg in 1931 (4) describes the first reported experiments in which typical heart rot symptoms were produced by depriving Eckendorfer fodder beets of the element boron. His lead to the study is credited to recent physiological investigations with other plants, including the work by Brenchley and Warington (7) which demonstrated that plants of *Vicia fabia* deprived of adequate boron became diseased in a manner similar to that of sugar beets affected with heart rot.

In his initial experiment, plants from sterilized seeds were grown in glass vessels containing v.d.Crone's solution (pH 6 to 7). By the addition of 0.5 to 0.7 mg per liter of boric acid to this nutrient solution, heart rot symptoms were eliminated. The results of later experiments in the greenhouse and field by Brandenburg (5, 6) corroborate and amplify his early findings. The symptoms described were very much the same as those described by Gaumann (16), and already outlined in this paper.

Field experiments reported in 1932 by Brandenburg (5) included applications ranging from 2 to 20 kg per hectare, and showed that an application of 3 kg per hectare of boric acid (about 2.7 pounds per acre) gave optimum results. An increase in yield of 34.8% over the control acreage resulted. Another report by the same author in 1935 (6) indicates complete control of heart rot in field experiments in Holland and Germany by application of 20 to 25 kg per hectare of boric acid. The beneficial effects were found to persist the second year. A survey reported in the same paper found the sandy soils throughout the southern province of Holland to be more or less deficient in boron. Analysis of the ash of healthy beets showed a content of 0.36 to 0.442% boric acid while the ash of diseased beets contained only 0.105 to 0.287%.

Studies by Kotila (22), Kotila and Coons (23) and Coons (10) were undertaken after their discovery of the disease in 1932. For almost a year the nature of the disease remained somewhat a mystery. Kotila suspected lightning injury when the specimens examined were found to be free from pathogenic organisms, but decided on further study that the conditions noted were not characteristic of lightning injury. When reports of European workers finally appeared in the literature and came to their attention, experiments were started at once which verified the suspected boron relationship. The symptoms described are the same, if not more inclusive, than those described by European workers.

Kotila (22) stated that Michigan soils seem to have enough boron to maintain normal growth until early August, and that affected plants are usually found on knolls or elevated portions of fields. A cursory survey (23) of some of the lighter soils with porous subsoils, found to be most deficient in boron, indicated occurrence of symptoms in severe form in as much as 15% of the stand of beets, and in incipient stage in at least 25% of the remaining stand.

Gram (18) found that heart and dry rot of sugar beets and mangels was prevented by application of 15 kg per hectare of borax. The more profitable application of 30 kg per hectare gave a toxic residual effect the second year. Jamildinen (21) reported from Finland that 5 kg of boric acid per hectare reduced the number

of diseased plants from 49.1% to 7.6% and increased yields from 11.4 to 20.8 metric tons per hectare.

Observations and experiments by Wimmer and Ludecke in Silesia (38) for the three year period, 1929–32, did not support the idea that boron deficiency is the cause of heart rot. Likewise, Solunskaya (35) attempted to discredit the general observation of other workers that alkalinity is conducive to a deficiency of boron by chemically "tying up" the soil supply of boron. The greater foliage produced under alkaline conditions, she explained, demands a greater supply of boron and hence the deficiency.

That parasitic fungi play only a secondary role in heart rot was aptly demonstrated by Hirsch (20) who inoculated at the same time normal, healthy beets and boron deficient beets with active cultures of three different species of rot fungi. There was no appreciable effect on the healthy beets whereas the latter showed a marked acceleration of heart rot. Observations by Bergenin and Foex (2) indicated that boron deficiency predisposes the plant to invasion by *Phoma betae*.

EXPERIMENTAL

Three different experiments conducted in the greenhouse and laboratory are reported in this paper, as follows: (a) Studies with sugar beet seedlings grown in sand cultures, (b) studies with field-grown sugar beets which showed marked boron deficiency symptoms, and (c) experiments designed to furnish information on the solubility of borax after application to the soil.

SEEDLINGS IN SAND CULTURES

The object of this experiment was to produce for observation and study the symptoms of boron deficiency at various stages of development. Seedlings germinated from commercial sugar beet seed were transplanted into glazed, 1-gallon, earthenware jars. Each jar contained 5 kg of a fine white silica sand, thoroughly washed with water but otherwise not purified. The moisture content of each jar was maintained at 10% by the daily addition of distilled water. Uniform seedlings were selected, and three were planted in each jar.

Only C. P. chemicals were used in the basal nutrient solution. In no cases did the analysis of the chemicals indicate the presence of boron. The basal nutrient treatment formulated and applied in essentially the manner outlined by Muckenhirn (28) contained a desirable application of all minor elements other than boron. Boron was applied in the form of $Na_2B_4O_7.10H_2O$ (borax) at rates of 0, 1.2, 2.4, 3.6, 5.9, and 11.9 mg per jar. Each treatment was replicated four times. After heart rot had appeared in severe form in the control plants, a moderate application of boron was made to determine whether or not a recovery would occur.

FIELD-GROWN BEETS IN SAND CULTURES

The beet roots used in this experiment were taken from fields the second week of October, just prior to harvest. They were chosen as specimens showing the characteristic symptoms described in the literature as boron deficiency. Presumably, the soil supply of available boron was inadequate to normal maturation in the latter part of the growing season, and it was on the basis of this assumption that an experiment was set up to prove or disprove that boron was the limiting factor.

Eleven roots showing definite and fairly uniform heart rot or deficiency symptoms were chosen. The entire foliage was removed close to the crown, as it

is with mother beets in preparation for seed production. The beets were then split in half and transplanted into 1-gallon, glazed, earthenware jars, filled with a convenient amount of white silica sand. One-half of each beet was transplanted to a jar receiving the basal nutrient solution, complete except for boron. The other half was placed in a jar which received in addition $Na_2B_4O_7.10H_2O$ (borax) at the rate of 2.4 mg per jar. Under regulated conditions of moisture, the growth of the half beets was observed in the greenhouse for a period of about 4 weeks, after which there seemed to be little further development. The relative development of corresponding halves was carefully noted in the course of the experiment and any abnormal habits of foliage resembling deficiency symptoms were followed closely. Additional stimulating amounts of boron were applied to the jars at the end of the first 4 weeks and at subsequent intervals thereafter.

BORAX SOLUBILITY IN NATURAL SOILS

As result of certain experiments not reported in this paper, some pot cultures were available which were of slightly acid Napanee loam and slightly alkaline Thomas sandy loam, and on which two crops of sugar beets had been grown after applications of borax at rates ranging from 2.5 to 80 pounds per acre. It was thought that soil tests for available boron made on these cultures after they had been standing for approximately one year might reveal information regarding the possibilities of boron accumulation in soils.

Further information on the chance for boron accumulation was obtained by analyzing leachates from these 1-year-old pot cultures. To obtain the leachates the pots were kept flooded with distilled water until a certain quantity of solution had passed through a small hole near the bottom of each pot. The leachate was collected in 2,500 ml. portions. The quantity of B_2O_3 in each portion was separately determined according to the method described below.

METHODS OF ANALYSIS

The soil analyses were made, except for minor variations, according to the method described by Cook and Millar (9). A smaller sample of soil was used, but the proportion of extracting solution to soil was the same. The extraction was made with 0.02N HCl instead of a weak solution of H_2SO_4.

The distillation procedure was essentially the same The boron in the anhydrous extract was distilled as methyl borate from an acid solution of absolute methyl alcohol into water made alkaline with Na_2CO_3. In alkaline solution the volatile methyl borate is hydrolyzed to a non-volatile form and can thus be retained in solution for titration. Rosolic acid (aurin) was used as the indicator in the micro-titration.

Analyses for sucrose were made under supervision of the Experiment Station chemist. Horne's dry lead acetate method was used for precipitation of impurities, and the sucrose content of the samples was determined with a 400 ml.-tube polariscope. Impurities of each sample were determined with the dipping or immersion type refractometer before sucrose determinations were made.

RESULTS AND DISCUSSION

SEEDLINGS IN SAND CULTURES

That boron plays an essential role in the growth and development of sugar beets is definitely shown by the results presented in Table 1.

The average yield from replicated jars receiving 11.9 mg borax in two applications was 80% greater than the average yield from control jars. The maximum concentration of borax at any time in the period of growth of the seedlings in this experiment was around 12 mg per liter of nutrient solution.

TABLE 1.—*Influence of different concentrations of boron on the yield of sugar beet seedlings grown in quartz sand and cultures.**

Treatment†	Relative yields			Symptoms developed	
	Tops and roots	Tops	Roots	Tops	Roots
No boron	100	100	100	Marked deficiency	Same
1.2 mg $Na_2B_4O_7.10H_2O$ at outset	148.8	146.4	151.1	Deficiency	Same
4.8 mg $Na_2B_4O_7.10H_2O$ after severe deficiency became evident	118.8	114.8	122.8	Deficiency on first growth	Same
7.1 mg $Na_2B_4O_7.10H_2O$ in divided applications	150.7	150.4	151.0	None	None
11.9 mg $Na_2B_4O_7$ $10H_2O$ in divided aplications	182.4	184.7	180.0	None	None
23.8 mg $Na_2B_4O_7.10H_2O$ in divided applications	177.4	191.3	163.5	Slight toxicity	None

*Yields of controls are represented by 100 and all results based on the average green weight of four replicates per treatment.

†All jars received equal applications of the basal nutrient solution.

On the basis of the growth and development noted in the greenhouse seedlings, it appears that the seedlings grown in jars which received 11.9 mg borax per jar had the nearest to an optimum application. When the application was increased to 23.8 mg borax per jar there was no indication of toxicity except for a slight but hardly significant depression in the yields of tops and roots. Considerably larger applications could probably have been made without serious toxic effects. Sugar beets are apparently able to withstand heavy applications of borax without suffering any ill effect. The requirement of the crop for boron seems to be very high. Dennis and O'Brien (11) found that, compared to other crops, sugar beets possessed an unusual tolerance for high concentrations of H_3BO_3. The Gramineae absorb and require very small quantities of boron while the Leguminoseae require considerably more. The Chenopodiaceae, represented by the sugar beet, are near the top in the plant list in boron requirement. Analyses by Bertrand and DeWaal (3) of plants grown in the same soil show 75.6 mg boron per kg dry matter for sugar beets compared to less than 5 mg per kg for five different Gramineae examined. It seems logical that plants with a high boron requirement should be resistant to injury from high concentrations of the element.

The first symptoms of deficiency were observed on the youngest center leaves of the untreated plants about 2 months after the seeds were planted. Apparently there was enough boron in the sand and in the seeds to satisfy the needs of the seedlings for the first 2 months. An apparent restriction of growth of certain portions of the center leaves caused a curling and twisting that contrasted sharply with the larger normal leaves of plants which received an adequate application of borax at the start of the experiment. A breakdown of the petioles of the leaves was also observed early in the growth period. The darkening of the inner or concave side was accompanied by pronounced cross checks near the base of the petiole.

As the state of deficiency was prolonged, the darkened areas extended well into the midribs of larger leaves and could be observed in cases to affect the lateral veins or smaller branches of the leaf's circulatory system. The cross checking characteristic of the petioles seemed to be replaced by a linear checking or blackening as the brittle condition extended farther into the midribs.

Another striking condition observed with plants deficient in boron was the very dark green color of their leaves compared to the leaves of healthy plants. As daily additions of water were made, it was repeatedly observed that the boron-deficient plants were subject to rapid wilting. The blackening and checking of extreme cases gave way to a yellowed condition of midrib and veins in less severe cases, contrasting sharply with the somewhat whitish color of veins in healthy plants.

Schmidt (33) concluded that the unusually dark green color of the foliage of plants receiving insufficient boron and other associated conditions are caused by unregulated nitrate absorption. He observed that with less nitrate in the culture solution provided sugar beets, the deficiency symptoms were less severe, and reported similar results with varied nitrate levels in field experiments. Presumably, in the absence of boron, nitrate ions crowd into the cells until their concentration is sufficient to cause a breakdown of protoplasm and progressive necrosis. It is the apparent function of boron properly to regulate nitrogen intake and thus prevent this disorder.

In the fairly early stages of development of deficiency symptoms, the growing point and tips of the smaller heart leaves gradually turned black and died back until the entire growing point of the plant was killed. Closer examination in the advanced stages of the disorder showed that the blackened condition extended into the heart of the beet root. As the large outside leaves gradually yellowed and also died back, a stunted second growth of foliage was produced around the crown of the beet. The second-growth leaves remained green for a short time, probably as long as demands for boron were being partially supplied by the root and then turned black or yellow.

Brandenburg (4) showed by analysis that ash of sugar beets diseased with heart rot contained only 0.105 to 0.287% of H_3BO_3 compared to 0.36 to 0.442% in ash of healthy beets. This difference probably explains why second-growth leaves are short lived on diseased roots where there is no outside source of boron. The beet shown at the right of group 1 in Fig. 1 shows the manner in which recovery

growth is produced around the edge of the crown and not out of the dead heart of the beet.

After second-growth leaves of beets growing in the eight jars of the check series had attained their ultimate development, 4.8 mg of borax were applied to each of four jars, in order to determine if the plants even in this very advanced stage of deficiency might be revived or stimulated. Slowly, but positively, the plants in the four jars that were given borax put forth new leaves around the crown of the beet. So significant was the stimulation that the average yield of roots for these four jars was 22.8% greater than the average yield for the four jars never receiving any borax. As will be pointed out in results from another experiment, the recovery and additional yield would probably have been more pronounced if the application of boron had been made sooner. No positive symptoms of deficiency were observed on plants of other series receiving the applications of borax specified in Table 1.

Prominent symptoms of heart rot in sugar beets are shown in Fig. 1. By actual observation of the diseased and healthy roots, it was much more apparent than the pictures indicate that the fibrous root system had been materially restricted by the lack of boron. The

Fig. 1.—The beet roots on the left, grown in sand culture without any added boron, show marked deficiency symptoms, including necrotic areas, restricted fibrous root system, second or recovery foliage growth around crown, and blackening of tissue under the skin. The normal roots on the right were grown under adequate levels of boron.

fibrous roots of the deficient specimens were much shortened and the blackened tips seemed definitely to indicate that boron deficiency had the same effect on meristematic tissue of the roots as of the stems. The first part of the stem affected was observed to be the growing point and the relatively later observation of roots showed that the growing point likewise was first affected. O'Brien and Dennis (29) found that the fibrous roots of swedes grown in culture solutions did not develop if boron was lacking.

The cutaway section of one diseased specimen pictured shows a characteristic darkened layer underneath the skin that probably develops in even later stages than the physiological breakdown of the heart of the root. A more advanced stage of this brownish colored layer is shown at the extreme left in Fig. 1. The fluid or solvent condition in sand cultures might cause a more complete breakdown of the affected area than would occur under normal soil conditions of growth. The healthy specimens, shown at the right in Fig. 1, are representative of the shorter, more stocky roots developed under ample applications of boron.

If various rot organisms, such as *Phoma betae*, contributed to the breakdown of tissue and the development of other characteristic symptoms observed, it seems very evident that they were a secondary factor and that the primary or predisposing factor was boron deficiency. No signs of necrosis or abnormal coloration of tissue were detected in the beet roots properly supplied with this element. No efforts were intended or made to maintain a sterile medium for growth. The only known difference among culture series was in the content of boron.

FIELD-GROWN BEETS IN SAND CULTURES

The results of this experiment prove quite conclusively that boron was a factor of first importance in the development of heart rot in the beets selected from infested fields in the fall of 1937. All roots used in the experiment were affected to a severe extent with a diseased condition fitting closely the literature's description of "heart rot" or "boron deficiency". The degree of severity is noted in Table 2 for the 11 specimens used.

The condition of the half beets about one month after they were transplanted to sand cultures is shown in columns 3, 4, and 5 of Table 2.

Eight of the 11 halves receiving the small stimulating application of boron when transplanted October 17 had produced and maintained foliage free of obvious deficiency symptoms. Two of the other three halves had produced reasonably vigorous foliage but showed slight deficiency symptoms. The third failed to produce new leaves.

It was interesting to note, as was observed in the experiment with seedlings already described, that deficiency symptoms did not appear before about 10 days on the duplicate halves of beets receiving no borax at the outset. This observation seems to indicate again a limited available source of boron in the sand or in the root itself for the growing of leaves. Leaf development was insignificant after deficiency symptoms began to appear and the death of the whole crown was

TABLE 2.—*Response of diseased sugar beets to applications of boron.*

No. of jar	Diseased condition of beet when transplanted Oct. 17	Condition of foliage Nov. 12			"B" jars showing new leaves Nov. 15*	Condition of foliage Dec. 14		
		Vigorous; healthy	Medium vigor; deficiency symptoms	Stunted; severe deficiency symptoms		Vigorous; healthy	Medium vigor; deficiency symptoms	Stunted; severe deficiency symptoms
1	Very severe			No growth				Dead
1B†	Very severe			No growth				Dead
2	Medium			×	×	×		
2B	Medium	×				×		
3	Severe		×			×		
3B	Severe	×				×		
4	Severe			×	×	×		
4B	Severe	×				×		
5	Medium		×			×		
5B	Medium	×				×		
6	Severe			×	×	×		
6B	Severe		×			×		
			No symptoms					
7	Very severe			×				Dead
7B	Very severe		×					Dead
8	Severe			×	×			Dead
8B	Severe	×				×		
9	Severe			×	×	×		
9B	Severe	×				×		
10	Medium			×	×	×		
10B	Medium		×			×		
11	Very severe			×	×	×		
11B	Very severe	×				×		

*Three days after application of boron to all jars
†The half beets in jars identified by "B" received boron when transplanted to sand culture October 17, while the corresponding halves received none until November 12.

eminent on November 12, when the two representative specimens shown in Fig. 2 were photographed. The information presented in Table 2 shows that all of the 10 halves that started growth without added boron developed definite deficiency symptoms.

FIG. 2. -Abnormal foliage produced by halves of boron-deficient beets after 3 weeks in sand culture without added boron. Characteristic symptoms include blackening and death of numerous shoots around diseased crown, crinkled and distorted leaves, cross checking, and blackening of midrib and veins.

The amazing recovery of the sick specimens after application of 2.4 mg of $Na_2B_4O_7.10\ H_2O$ per jar was taken as further proof that boron was the controlling factor in the abnormal condition. Only 3 days after the boron was added, seven of the nine halves that ever recovered were showing vigorous green shoots to replace the dead or nearly dead foliage. The extent to which new leaves developed during the month following the application of boron is shown by Fig. 3.

The stimulating effect of the second application of boron to jars receiving a small application in the beginning was also noted. So small was the first application that its near depletion was reflected in the slowed growth of foliage on these halves of the beets. Based on the response observed, there seems little doubt that a continuous supply of the element is essential and that its role is, therefore, not merely catalytic.

The results of this experiment and the experiment with seedlings in sand cultures have indicated that when applications of boron are too long delayed after the plant shows starvation symptoms it will not revive as completely or make as large a growth as it would have if the borax had been applied before any deficiency symptons occurred.

SOLUBILITY OF BORAX IN SOIL

In the field application of borax it is well to consider residual effects or cumulative tendencies. In the case of sugar beets, a crop that withstands relatively large applications of borax without in-

FIG. 3.—Mother beet, before and after addition of borax to nutrient solution. A, Characteristic "dead" crown showing advanced stages of dry heart rot. The twisted, distorted leaves and other symptoms suggest a serious effect of boron deficiency on the circulatory system of the petiole and midrib. Photograph taken Nov. 9. B, The same beet photographed Dec. 10 after 5 p.p.m. of $Na_2B_4O_7 \cdot 10H_2O$ had been added to the nutrient solution. Healthy leaves had replaced those shown in A.

jury, there seems little danger, with reasonable applications, of building up in the soil an undesirable reserve of boron. However, other

crops generally featured in a rotation on sugar beet soil are decidedly sensitive to boron and have to be more carefully considered. The cereal crops and grasses are especially sensitive and it has been shown that legumes require less boron than do sugar beets.

According to the results presented in Table 3, the production of two crops of sugar beets significantly reduced the quantity of boron which could be extracted from the soil by warm 0.02N HCl. This would indicate that a crop of sugar beets might be expected to remove a rather large part of the borax during the year when the application was made.

TABLE 3.—*The effect of cropping with sugar beets on the available B_2O_3 content of Napanee loam pot cultures.*

Treatment and extent of cropping	B_2O_3 in 25-gram samples of soil, av. of 4 pots, mg
Untreated, uncropped	0.065
Untreated, after two crops	0.053
Borax 76 mg per pot, after one crop	0.094
Borax 76 mg per pot, after two crops	0.067
Borax 304 mg per pot, after one crop	0.216
Borax 304 mg per pot, after two crops	0.172

To see whether or not the borax which remained in the pot cultures was soluble in water or was tied up in the soil in an insoluble form, the pots were subjected to leaching with distilled water after the second crop was removed. This was accomplished by keeping the pots flooded and catching the leachate from a hole at the bottom of the jar. As an average, 2,500 cc of leachate from the eight untreated Napanee soil cultures contained 0.85 mg borax, while the same volume of leachate from the eight pots which received 80 pounds of borax per acre contained 20.27 mg borax. In the case of the Thomas soil two successive 2,500-cc leachings were made on four untreated and four treated pots. From the untreated pots the two successive leachates contained as an average 1.126 mg and 0.86 mg borax, respectively, while from the treated pots the respective quantities of borax were 7.83 and 3.45 mg.

Although no attempts were made to leach these cultures completely, and while it is fully realized that the leaching was rather crudely done, the figures show that after 14 months in the soil the borax was still quite soluble in distilled water. Still greater quantities would no doubt have been removed if the leaching solution had been carbonic acid as is the case when field soils are leached with rain water. The effect of carbonic acid was shown by leaching tests conducted by Cook and Millar (9). They showed that a much greater quantity of boron was removed from soil by a carbonic acid solution than was removed by distilled water.

These data from the soil and leachate tests compare favorably with the results from extensive leaching tests conducted by Krugel, *et al.* (24) who showed that borax and boric acid applied with superphosphate were leached from the soil to the extent of 77.6 and 78.7%, respectively. They showed also that a normal beet crop removed

4 to 5 kg of borax per hectare when treated with 16 to 20 kg of borax per hectare.

Under such rapid absorption by the crop and the leaching to which humid soils are subjected, the possibility of boron accumulation to the point of toxicity seems less serious than might be supposed.

SUMMARY AND CONCLUSIONS

Sugar beet seedlings were grown in quartz sand cultures with and without borax. Symptoms of boron deficiency were carefully observed and studies were made regarding the recovery of beets afflicted with heart rot.

Field-grown mother beets showing heart rot symptoms were divided into halves and planted in quartz sand cultures, with and without borax applied at various times during the subsequent growth period. Observations were made on the types of leaves produced by these mother beets.

Soil and leachate tests were made to determine the extent of absorption of boron by sugar beets and the state of solubility of the boron remaining in the soil. This was done to throw some light on the possibility of boron accumulation in the soil From the results of these experiments the following observations were made:

1. Seedlings grown in jars receiving no borax developed characteristic deficiency symptoms as follows:
   a. Blackening of tips of heart leaves, followed by death of growing portion of crown.
   b. Shortened, twisted petioles associated with crinkled condition of heart leaves and some of outer leaves.
   c. Abnormally dark green and thicker leaves, accompanied by more rapid wilting under drought conditions.
   d. Pimpled condition of petioles in early stages, followed by breakdown in form of cross and linear checking.
   e. Yellowing and eventual death of outer leaves, following the death of heart leaves.
   f. Stunted, second growth leaves following death of first leaves.
   g. Breakdown of heart of beet root.
   h. Darkened layer under skin of root and development of surface cankers in advanced stages.
   i. Restricted fibrous root system.
2. The available boron content of the quartz sand and the seed was adequate to prevent the appearance of deficiency symptoms for a period of two months after the seedlings were transplanted.
3. Yields of roots were increased as much as 80% by an application of 11.9 mg of borax per 5 kg of sand in divided applications.
4. Seedlings in advanced stages of heart rot definitely recovered upon the application of 4.9 mg of borax per pot.
5. Halves of field-grown mother beets planted in quartz sand cultures without borax produced stunted leaves with marked symptoms of boron starvation, whereas the corresponding halves which received like treatment but with borax added at the rate of 2 mg

per 1-gallon pot, produced a more abundant leaf growth free of deficiency symptoms.

6. Soil tests for available boron showed that a crop of sugar beets produced in pot cultures removes an appreciable quantity of boron from the soil.
7. By determining the quantity of B_2O_3 in leachates from pot cultures it was found that it was relatively easy to remove added borax from soils by leaching with distilled water even a year after the borax was applied.

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RESISTANCE OF CORN STRAINS TO THE LEAF APHID, *APHIS MAIDIS* FITCH[1]

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THE resistance or susceptibility of strains of corn to the corn-leaf aphid (*Aphis maidis* Fitch) has been observed at several locations in Illinois over a three-year period, 1937–39. Data presented here indicate the possibility of reducing injury caused by this insect through the use of resistant strains of the host.

Because efficient controls of the corn-leaf aphid can not be effected economically on a field basis by cultural practices, the use of insecticides, or by other methods useful in the case of a number of other insect pests, it is necessary to seek other solutions of the problem. One of the most promising methods of control involves the utilization of resistant strains now available and the breeding of new resistant strains of corn.

In Illinois, the corn-leaf aphid usually is present sometime during the growing season each year. This insect is not always present in sufficient numbers to cause serious loss and the type of damage usually is not spectacular. For that reason, damage by it is often not considered serious. However, under conditions of a light infestation the damage done by the leaf aphid is another factor that prevents maximum development of the corn plant. Heavy infestations sometimes result in the complete failure of grain development either by death of the plant or by destruction of the tassel which prevents pollination of the silks. In other cases ear-shoots may fail to develop on plants that have heavy infestations of aphids in the tassel, even though there are sufficient uninfested plants present to furnish pollen. This was observed in the hybrid performance test grown at Libertyville, Ill., in 1938 which was infested with leaf aphids. Data were obtained from five random plots of each of 60 different entries in this test. Only 1.2% of the entire plant population of the field was infested, but the plants that were infested had many aphids confined almost entirely to the tassels. This condition enabled normal pollen shedding from 98.8% of the plants in the field. Counts indicated that 48.1% of the infested plants were barren. It was estimated that only 1 to 2% of the uninfested plants were barren. These data indicate very strongly that aphids feeding in the tassel have a physiological effect upon the corn plant which retards or prevents development of the ear-shoot.

The corn-leaf aphid is an especially serious problem in the production of foundation seed stocks for use in the production of commercial

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hybrid seed corn. Inbred lines are normally weak, and a moderate infestation of aphids on a susceptible to moderately susceptible line may prevent satisfactory pollination of the ear parent, even though complete destruction of the pollen parent may not occur. For that reason considerable time has been devoted to a study of inbred lines, the results of which are presented here. A detailed description of the manner in which the corn-leaf aphid injures the host is omitted since this subject has been discussed in a number of publications dealing with this insect.

REVIEW OF LITERATURE

Host resistance as a means of reducing aphid injury has been used for several years with a number of crop plants and has been suggested as a control for several others.

The use of resistant vines as a control for the grape Phylloxera is a classic example of host resistance to insect injury. Bioletti (2)[3] and Twight (28) urged the use of resistant vines as the most satisfactory method of combating Phylloxera in California, because it is applicable to all conditions. Bonnet (5) reports that while the American grape species usually are considered resistant to Phylloxera the different species vary from practically complete immunity to a susceptibility little less than that of *Vita vinifera*, the European species which is extremely susceptible. This variability among American vines in susceptibility has also been mentioned by Topi (27). Borner (6) has shown that several American vines are resistant to Phylloxera under conditions in Germany and suggests that in resistant-susceptible crosses resistance appears to act as a Mendelian dominant. According to Feytaud (12), the discovery of the resistance of American vines in 1869 eventually solved the problem of Phylloxera in Spain.

Since the discovery of immunity of Northern Spy apple to the woolly aphid many papers have been written on the use of host resistance as a means of combating damage caused by this insect. This insect is almost as widespread as the apple itself, and recommendations on the use of resistant stocks are numerous. Theobald (26), Staniland (25), Tydeman (29, 30), Le Pelley (18), Hatton (16), Massee (20), Greenslade, Massee, and Roach (15), and Crane, *et al.* (8) have all reported on resistance to this insect in England. Bremer (7) advocates the use of resistant stocks as a solution of the woolly aphid problem in Argentina, while Jancke (17) and Speyer (23) have reported on the resistance of apple varieties in Germany. Monzen (21) has published on the immunity of *Prunus prunifolia* and the susceptibility of *Prunus sieboldi* (toringo) in Japan, while Becker (1) has reported on experiments with woolly aphid resistance in this country.

Other outstanding cases of aphid resistance in a fruit crop have been reported by De Long and Jones (11), selections of Houghton gooseberry immune to the gooseberry aphid, Spinks (24), and Darrow, Waldo, and Schuster (9), varieties of strawberries resistant to the strawberry aphid, and Winter (31), the marked resistance of Herbert raspberry to *Amphorophora rubi*.

Reports of aphid resistance in field crops are less numerous, but sufficient cases have been reported to indicate that the use of resistant varieties of field crops may be of as much importance in the control of aphids as is the case with fruit crops. Davidson (10) reports that plants of *Vicia narbonensis* are highly resistant to *Aphis rumicis*, while in a study of 18 varieties of *Vicia faba* he found the grade

[3]Figures in parenthesis refer to "Literature Cited", p. 380.

of susceptibility ranged from 3 to 98%. He also indicates that resistance or susceptibility may be largely determined by genetic factors in the plant. Blanchard and Dudley (3) and Blanchard (4) have reported on the presence of plants of alfalfa that are highly resistant to the pea aphid, *Illinois pisi*. Searls (22) has shown that Onward and Perfection, varieties of canning peas, are resistant to the pea aphid, while Yellow Admiral is susceptible. He also presents data which indicate that resistance is associated with a yellowish green foliage color, while susceptibility is associated with dark green foliage color.

A review of the literature indicates that very little data have been published on aphid resistance in corn, but the papers that were found were in general agreement with data presented herein. Forbes (13) has reported experiments where attempts were made to rear the corn-leaf aphid on different host plants such as corn, wheat, grass, purslane, and apple. Gernert (14) reported on the aphis immunity of teosinte-corn hybrids. He found teosinte to be immune to the corn-leaf aphid, *Aphis maidis*, and the corn-root aphid, *Aphis maidi-radicis*, while the yellow dent corn used was very susceptible to both species. The F_1 plants showed the immunity of the teosinte parent, indicating that resistance was dominant in the first generation.

McColloch (19) has published on the resistance of varieties of open-pollinated corn to *Aphis maidis* in Kansas. He observed that the amount of aphid injury tended to increase with the lateness of the variety but that certain varieties having about the same maturity range varied rather widely in their aphid resistance. The observations of McColloch concerning the tendency for injury to increase with the lateness of the variety have been confirmed by the writers under conditions where the infestation of aphids did not develop before the tasseling period of early strains of corn. Lignification of the peduncle and other tassel parts tends to discourage aphid feeding although the plant otherwise might be susceptible. A reverse condition is also possible when natural enemies of the corn-leaf aphid reduce the infestation and thereby allow late tasseling varieties to escape severe damage.

Aphids as a group are very sensitive to the condition of the host plant as well as other environmental factors. These conditions must be recognized and considered in the determination of the resistance of a group of corn strains. Under the conditions of the present experiments it was believed that strain resistance is not the result of evasion, except perhaps in a few cases where records for only one year were available. Portions of these data have been studied with reference to the relationship between time of tasseling and percentage of plants infested. The coefficient of correlation computed from the data on 31 of the inbred lines was -0.21 ± 0.01, far from a marked value.

MATERIAL AND METHODS

A cooperative project for the study of insect resistance in corn and for the development of resistant strains was established in Illinois in 1937. Since that time annual plantings have been made of a large number of strains of corn for a study of injury by the major corn insect pests. Positive assurance of a sufficient infestation of the insects being studied can not always be determined in advance of planting time, and for that reason plantings have been made at several locations each season. The data presented here have been collected at Urbana and Oakwood in central Illinois and at McClure in extreme southern Illinois, approximately 240 miles south of Urbana.

At Urbana in 1937, data were obtained on a number of strains grown in single row plots replicated in four randomized blocks. Each plot consisted of 10 hills. Fifty-one inbred lines, 69 single crosses, 34 double crosses, and 66 open-pollinated varieties were available for study. In 1938 plantings were made at Urbana, Oakwood, and McClure. These plots consisted of duplicated and triplicated single row plots, 10 hills long. Aphid studies at these locations were confined mainly to inbred lines and single crosses. Urbana and McClure were the locations where plots were grown in 1939. Data were obtained at Urbana on aphid damage, but the infestation at McClure was not sufficient in the plots to permit differential readings.

The method of determining infested plants was by examination of recently emerged tassels for the presence of aphids. While the data presented here deal largely with the total percentage of plants infested, the severity of the infestation was determined on all infested plants and they were classified in three grades designated as light, medium, and heavy. The light class usually included plants upon which a rather small number of aphids were found, while the medium class included plants having a moderate infestation. The heavy class included plants with many aphids, and considerable damage was often evident on the upper leaves of the plant, as illustrated in Fig. 1. In most cases, there was a very close association between the degree of infestation and the total percentage of plants infested. A study has been made concerning this relationship on a portion of the data presented here. An injury index was determined by placing a penalty on plants having heavy damage. The percentage of plants showing heavy damage was multiplied by 3, while those classes with moderate and light infestations were multiplied by 2 and 1, respectively. These weighted percentages then were added together to obtain an injury index. The relationship between the injury index and the total percentage of plants infested was measured by computing the coefficient of correlation between them. The value of r was found to be 0.98 ± 0.006, and with this close association it is believed that the total percentage of plants infested is a fairly reliable measure of the resistance of a given strain of corn. A few exceptions were noted and will be discussed later in this paper. However, these exceptions were so few it is believed unnecessary to present the entire data showing severity of infestation.

RESULTS

The percentage of infested plants of yellow inbred lines is given in Table 1. The data obtained from white inbred lines are presented in Table 2. The intensity of the general infestation of aphids fluctuated rather widely with both location and season. In spite of this range in severity of infestation there is general agreement in the relative infestation of the different inbred lines in the different experiments. The coefficients of correlation indicate a reasonably close association of the relative ranking of the inbred lines grown at different locations. The r value computed from the data on 22 inbred lines grown at Urbana in 1937 and at Oakwood in 1938 was 0.75 ± 0.06, while an r value of 0.81 ± 0.06 was obtained for 14 inbred lines grown at Urbana in 1937 and at McClure in 1938.

The percentage of plants infested at Urbana in 1937 ranged from 0 to 90.0 for inbred 5356-3. The general level of infestation at Urbana in 1938 was higher than in 1937, ranging from 0 to 100% for five inbred lines. The maximum infestation of 67.5% for line 5120 at

McClure in 1938 indicates that the infestation there was less severe. Six of the inbred lines tested at McClure were free of any infestation. The infestation at Oakwood in 1938 was considered as very good for

FIG. 1.—A tassel of a plant of inbred 5356-2 showing a heavy infestation of corn-leaf aphids. The leaves have been killed and are void of green color. Pollen produced by this tassel became entangled in the honeydew secreted by the aphids and was not available for pollinating silks.

TABLE 1.—*Percentage of plants of yellow inbred lines infested with corn-leaf aphid.*

Inbred line	Origin	Urbana, 1937	Urbana, 1938	McClure, 1938	Oakwood, 1938	Average of 3 stations*	Average of 2 stations†
4226	Ill.	1.4	—	0.0	5.7	2.4	3.6
R4	Ill	1.8	—	0.0	5.6	2.5	3.7
B2	Ind.	0.9	33.3	7.9	20.0	9.6	10.5
WF9	Ind.	7.8	—	22.8	16.2	15.6	12.0
K4	Kans.	4.0	—	11.7	43.2	19.6	23.6
L317	Iowa	5.2	68.2	7.7	65.6	26.2	35.4
Hy	Ill.	7.6	56.5	29.4	44.1	27.0	25.9
Kys	Kans.	3.5	100.0	12.9	71.9	29.4	37.7
Pr.	Iowa	16.7	—	2.9	41.7	30.4	29.2
Tr.	Ind.	15.3	—	10.5	78.8	35.2	47.1
38–11	Ind.	31.7	92.3	2.6	74.4	36.2	53.1
540	U. S.	19.6	78.9	23.3	100.0	47.6	59.9
701	Iowa	66.0	100.0	37.5	100.0	67.9	83.1
5120	Ill.	85.4	94.7	67.5	96.5	83.1	96.0
51	Ohio	0.0	—	—	0.0	—	0.0
A	Ill.	0.0	8.3	—	9.7	—	4.9
L9	Ind.	5.2	—	—	21.9	—	13.6
90	Ill.	0.0	—	—	42.3	—	21.2
66	Ind.	37.3	—	—	62.0	—	49.7
5680	Ill.	37.1	—	—	63.2	—	50.2
5953	Ill.	68.4	—	—	94.0	—	80.2
5325–4	Ill.	62.6	—	—	100.0	—	81.4
K	Ill.	0.0	18.8	—	—	—	—
CC2	Wis.	0.0	—	—	—	—	—
5313–2–5	Ill.	0.9	—	—	—	—	—
5676	Ill.	1.0	—	—	—	—	—
2204	Ill.	2.9	—	—	—	—	—
5317–2	Ill.	4.9	—	—	—	—	—
5316–1–2	Ill.	6.5	—	—	—	—	—
CC6	Wis.	7.6	—	—	—	—	—
5675	Ill.	7.8	—	25.6	—	—	—
4211	Ill.	12.8	—	24.0	—	—	—
2203	Ill.	22.6	—	—	—	—	—
5678	Ill.	23.5	—	65.2	—	—	—
I198	Iowa	36.0	—	—	—	—	—
10	Ohio	45.0	—	—	—	—	—
5679	Ill.	46.7	—	—	—	—	—
5955	Ill.	57.0	—	—	—	—	—
4451	Ill.	72.6	—	—	—	—	—
5378–2	Ill.	81.8	—	—	—	—	—
5356–2	Ill.	85.8	—	—	—	—	—
5356–3	Ill.	90.0	—	—	—	—	—
56	Ohio	—	3.7	16.7	6.1	—	—
67	Ohio	—	44.4	0.0	—	—	—
28	Ohio	—	63.6	38.9	—	—	—
07	Ohio	—	100.0	22.8	—	—	—
02	Ohio	—	100.0	58.8	100.0	—	—
K 166	Kans.	—	89.3	0.0	—	—	—
15–6	Ohio	—	—	0.0	—	—	—
187–2	U. S.	—	—	0.0	—	—	—
I159	Iowa	—	—	15.4	—	—	—
I205	Iowa	—	—	19.4	—	—	—

*Urbana, Ill., 1937; Oakwood, Ill., 1938; McClure, Ill., 1938.
†Urbana, Ill., 1937, and Oakwood, Ill., 1938.

TABLE 1.—*Concluded.*

Inbred line	Origin	Urbana, 1937	Urbana, 1938	McClure, 1938	Oakwood, 1938	Average of 3 stations*	Average of 2 stations†
4-8	U. S.	—	—	53.0	97.2	—	—
CCl	Wis.	—	—	—	0.0	—	—
Fe	Ind.	—	—	—	0.0	—	—
C2	Ind.	—	—	—	10.5	—	—
KR100-5-1	Ind.	—	—	—	15.1	—	—
H6	Ind.	—	—	—	15.4	—	—
5110	Ill.	—	—	—	44.8	—	—
84	Ohio	—	100.0	—	88.9	—	—
Averages		27.3	67.8	20.6	48.0		
Range		0–90.0	3.7–100.0	0–67.5	0–100.0		

TABLE 2.—*Percentage of plants of white inbred lines infested with corn-leaf aphid, Urbana, Ill., 1938–39, and McClure, Ill., 1938.*

Inbred line	Origin of line	Percentage of plants infested			2-year average*	3-year average†
		Urbana, 1938	Urbana, 1939	McClure, 1938		
2075	Ky.	0.0	0.0	0.0	0.0	0.0
24	U. S.	2.9	8.0	—	5.5	—
50	Ky.	1.9	20.0	28.9	11.0	16.9
JC 33	Ind.	0.7	40.4	13.7	20.6	18.3
B103	Mo.	10.0	68.0	0.0	39.0	26.0
43	U. S.	14.3	69.7	—	42.0	—
13	Ky.	9.0	79.2	—	44.1	—
PS 6	Kans.	22.4	79.5	22.7	51.0	41.5
30A	Ky.	24.5	78.1	67.9	51.3	56.8
28	Ky.	23.1	100.0	—	61.6	—
62	U. S.	32.9	100.0	—	66.5	—
27	Ky.	37.8	100.0	34.2	68.9	57.3
11b	U. S.	39.6	100.0	42.4	69.8	60.7
21	Ky.	64.7	78.6	30.0	71.7	57.8
61	U. S.	51.6	100.0	—	75.8	—
39	Ky.	64.4	88.0	14.3	76.2	55.6
PS 22	Kans.	55.5	100.0	34.3	77.8	63.3
11a	U. S.	59.2	100.0	—	79.6	—
41	U. S.	63.8	96.7	—	80.3	—
23	U. S.	76.2	84.4	—	80.4	—
73	Ky.	71.4	96.0	—	83.7	—
122	Ky.	75.0	100.0	—	87.5	—
56	Ky.	80.9	100.0	—	90.5	—
89	Ky.	100.0	100.0	—	100.0	—
Averages		40.9	78.6	26.2		
Range		0–100.0	0–100.0	0–67.9		

*Urbana, 1938–39.
†Urbana, 1938–39; and McClure, 1938.

obtaining differential resistance data. The range in infestation was from 0 for inbreds 51, CCl, and Fe to 100% for inbreds 540, 701, 5325-4, and 02.

Many of the inbred lines were not grown during the entire period of these tests and for that reason dependable averages are limited to those lines grown in more than one year. Attempts were made to observe the resistance of lines of the most agronomic importance in the Corn Belt hybrid corn programs, hence less valuable lines have been eliminated from time to time and new and promising lines have been added. However, some of the older standard lines have been in most of the tests and a 3-station year average is shown for 14 inbred lines. A 2-year average is presented for 22 inbred lines.

White inbred lines grown in the white corn breeding nursery at Urbana were made available for aphid studies through the courtesy of Wayne H. Freeman of the Illinois Agricultural Experiment Station. Data on aphid resistance were obtained at Urbana on 24 of these inbred lines during 1938 and 1939 and on 11 of the same lines at McClure in 1938.

The general level of infestation at Urbana was higher in the white inbred nursery in 1939 than in 1938, but the more resistant inbreds were relatively free of aphids during both seasons, while the more susceptible strains were heavily infested both years. The level of infestation at McClure was not as high as at Urbana. Kentucky inbred 2075 was free of aphids at each location. The range in infestation at Urbana was from 0 to 100% during both seasons, while the range at McClure was from 0 to 67.9%. From the data shown in Table 2 it is evident that such inbred lines as Kentucky 2075 and U. S. 24 have rather high resistance, while Kentucky inbreds 122, 56, and 89 are susceptible.

Variations in aphid resistance and susceptibility have been sufficiently great among inbred lines that it was thought desirable to obtain data on the reaction of some of the lines in hybrid combinations. Table 3 presents data which indicate that aphid resistance is inherited. Sixteen inbred lines varying in their resistance to aphids were crossed with inbred 38-11, a moderately susceptible line in most tests although only 2.6% of the plants were infested in this test at McClure. Plots of the F_1 plants were grown at McClure in 1938, under aphid conditions. In general, the aphid resistance of the single crosses paralleled the aphid resistance of the inbred lines crossed with 38-11. Quartile averages were made of the percentage of plants infested in the inbred lines and the corresponding single crosses. The quartile averages for the single crosses were 8.4, 12.7, 22.3, and 43.0% of the plants infested as compared with 6.0, 9.9, 23.9 and 47.0% infested for the corresponding inbred lines crossed with 38-11.

The transmission of aphid reaction by inbred lines to their single crosses was studied further in another experiment. Six inbred lines, L317, 38-11, Hy, 540, R4, and WF9, were crossed in all possible combinations and the resulting single crosses, 15 in number, were tested under conditions of an aphid infestation at McClure in 1938. Data from this experiment are presented in Table 4.

The data in Table 4 indicate marked differences among the lines in the transmission of resistance or susceptibility to their hybrids. Single crosses involving WF9 were uniformly susceptible. Those involving Hy were resistant, except for the combination with WF9.

TABLE 3.—*Percentage of plants infested with corn-leaf aphid, crosses involving inbred 38-11, McClure, Ill., 1938.*

F_1 single cross	Total infested, %	Quartile average, %	Inbred line*	Total infested, %	Quartile average, %
38–11×Kys.	2.6	8.4	Kys	12.9	6.0
38–11×L317	4.9		L317	7.7	
38–11×187–2	7.3		187–2	3.2	
38–11×R4	10.8		R4	0.0	
38–11×07	11.4	12.7	07	22.8	9.9
38–11×67	12.2		67	0.0	
38–11×56	13.6		56	16.7	
38–11×15–6	13.6		15–6	0.0	
38–11×540	15.8	22.3	540	23.3	23.9
38–11×K166	20.0		K166	0.0	
38–11×4–8	25.6		4–8	53.0	
38–11×I205	29.7		I 205	19.4	
38–11×WF9	31.5	43.0	WF9	22.8	47.0
38–11×5120	37.2		5120	67.5	
38–11×28	39.0		28	38.9	
38–11×02	64.3		02	58.8	
Average	21.2			31.5	

*38–11 had 2.6 of the plants infested in this experiment

Line 38–11 seemed to have relatively little influence upon its hybrids, their response apparently being more largely determined by the other parents. A similar situation was obtained among the single crosses listed in Table 3.

TABLE 4.—*Percentage of plants infested by the corn-leaf aphid, six inbred lines tested in all possible single cross combinations at McClure, Ill., 1938**

Inbred line	L317	38–11	Hy	540	R4	WF9
L317	—	4.9	5.1	13.7	4.9	23.1
38–11	4.9	—	7.3	15.8	10.8	31.5
Hy	5.1	7.3	—	7.7	4.8	48.9
540	13.7	15.8	7.7	—	22.3	27.5
R4	4.9	10.8	4.8	22.3	—	69.4
WF9	23.1	31.5	48.9	27.5	69.4	—
Average	10.3	14.1	14.8	17.4	22.4	40.1
Percentage of plants infested	7.7	2.6	29.4	23.3	0.0	22.8

*Seed of the single crosses used in this experiment was supplied by G. H. Stringfield.

The data presented in Tables 3 and 4 indicate without question that resistance is inherited. There are indications that the response of the hybrids may in some cases be explained best on the assumption of complementary factors contributed by the two parents. However, it is recognized that these data are inadequate and that aphids are especially sensitive to the conditions of the host plant and other environmental factors, and for these reasons it does not seem advisable to draw further conclusions.

Further study is also needed concerning the method of measuring resistance. In general, the total percentage of plants infested seems to be a rather satisfactory indicator of resistance. This is especially true when the data are supplemented by classifying the intensity of the infestation on the individual plants of a population. In most cases, where plants have a high total percentage of infestation, they will also have a relatively high percentage of plants with large aphid populations. Inbred 701 (or 540) is an exception to this condition in that usually many plants are infested but seldom is the infestation heavy enough to interfere with pollination.

It was observed that some of the inbreds were not uniform in their resistance or susceptibility. Some of the lines tested appeared to consist of a mixture of reasonably homozygous resistant and susceptible plants with relatively few heterozygous individuals. The seed of the inbred lines used in these experiments consisted in many cases of bulk selfed seed (obtained by mixing the seed of many selfed ears) carried by the experiment stations. Apparently in some cases selfed seed of the lines had been mixed while still segregating for resistance and had since been carried by a procedure which involved the planting of this bulk seed, the selfing of numerous plants, and the mixing each season of the selfed seed obtained.

SUMMARY

Data presented here indicate the possibility of reducing injury caused by *Aphis maidis* through the use of host resistance.

The corn-leaf aphid is an especially serious problem in the production of certain foundation seed stocks which are for use in the production of commercial hybrid seed corn.

The infestation was determined by an examination of recently emerged tassels for the presence of aphids. Although the severity of the infestations was measured by classifying all infested plants in one of three infestation classes, in general the total percentage of infestation was considered as a reliable indicator of the relative resistance or susceptibility.

Data are presented from many yellow and white inbred lines as well as from a sufficient number of single crosses to indicate that resistance to this insect is a heritable character.

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EFFECT OF AWNS ON KERNEL WEIGHT, TEST WEIGHT, AND YIELD OF WHEAT[1]

B. B. BAYLES AND C. A. SUNESON[2]

THE coordinated wheat improvement experiments at 17 stations in eight western states (3),[3] have offered an excellent opportunity for a study of the performance of awned and awnless wheats under very diverse environments. The problem is of both theoretical and practical interest. Many of the previous experiments with wheat to determine the influence of awns on yield and kernel weight have not been conclusive and no attempt has been made to test similar material at more than one location. In general, awned plants have tended to produce heavier kernels and a higher weight of grain per plant, although this has not always been the case. Clark and Quisenberry (1) and Lamb (2) have reviewed the literature on the effect of awns in wheat.

The data on the effect of awns presented here were obtained from composite populations of awned and awnleted segregates from two crosses, one between two winter varieties and the other between two spring varieties. Material for another method of comparing awned and awnless wheats is being developed, but results will not be available for several years. This material is being produced by repeated backcrossing of awnless segregates with the awned parent and awned segregates with the awnless parent. It is planned to continue backcrossing until types similar to the two parents in all genetic characteristics except presence or absence of awns have been obtained. These should be better suited for further studies on the influence of awns on the development of the wheat kernel.

MATERIAL AND METHODS

In the experiments reported here composites of awned and of awnless or awnleted segregates from two crosses involving parents of considerable prominence in the western states were studied. Plants in the F_2 generation of the cross, Triplet ×Oro, grown at Moscow, Idaho, in 1933 were classified as awned, heterozygous awnleted, and awnleted. Samples totaling about 2 pounds each of seed of the awned and awnleted segregates were composited and planted at Pendleton, Ore., in the fall of 1933. Seed from this crop was distributed for seeding uniform yield trials in the fall of 1934, the first yields thus being obtained in 1935 on the F_4 generation.

A smaller F_2 population of the second cross, Baart×Onas, was grown at Aberdeen, Idaho, in 1933. Plants were separated into three classes, *viz.*, awned, heterozygous awnleted, and homozygous awnless or awnleted, and the F_3 generation of each class was grown during the winter at Tucson, Ariz., where the homozygous plants were again separated from the segregating population and added

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[3]Figures in parenthesis refer to "Literature Cited", p. 388.

to the respective true breeding composites. The F_4 generation of the awned and awnleted composites was grown at Aberdeen, Idaho, in 1934 from spring seeding. The seed stocks were rogued carefully and then grown at Tucson during the winter of 1934–35 and the resulting seed sown at Aberdeen, Idaho, in the spring of 1935. The F_7 and later generations were grown in uniform yield trials at several stations beginning in 1936.

Successive yield trials have represented a progressively smaller random portion of the original hybrid population in advancing stages of homozygosity. Seed for the subsequent tests of Triplet×Oro at all cooperating stations has been supplied from seed plots at Pendleton, Ore., and Pullman, Wash., and seed of Baart×Onas was produced at Pullman and at Aberdeen, Idaho. The yields and other data have been obtained from paired adjacent plots of awned and awnleted types included in uniform varietal nurseries from which yields and other agronomic data are summarized annually (3). Each nursery consisted of three 3-row plots with the rows 16 feet long and 12 inches apart. The center row only in each plot was harvested for yield. Planting rates varied according to commercial practice in each section. The one exception to the above procedure was in 1939 when tests of the Baart×Onas composites were made in nurseries consisting of five pairs of single 16-foot rows protected on the flanks by guard rows.

EXPERIMENTAL RESULTS

EFFECT OF AWN ON KERNEL WEIGHT

Comparative kernel weights from awnleted and awned plants for the 4-year period 1936–39 are shown in Table 1. These weights were obtained from random samples of whole kernels, consisting of five 100-kernel samples of each lot in 1936, three 1,000-kernel samples in 1937, and three 200-kernel samples in 1938 and 1939. Standard errors were about the same in each season. Some of the annual differences in kernel weights may be due to variations in moisture at the time of weighing, but all comparable pairs were stored together and weighed at the same time.

An average kernel weight difference of 0.8 milligram, or 2.6%, in favor of awned plants was obtained from the 36 comparable lots in the Triplet×Oro cross. Awned samples had a greater weight in 27 of the 36 tests. This distribution tested by the binomial method gives odds for a difference in favor of the awned type greater than 99 to 1. Since the binomial method of determining odds is easy to apply and since it is suited to comparisons of this kind, it is used throughout this paper. In this method magnitude of differences is ignored. Ties were divided equally between the two groups or if an odd number occurred, one was omitted.

Data are available from 42 station-year comparisons of the Baart× Onas segregates grown at non-irrigated and irrigated stations. Parents and hybrids in this instance represent true spring types of white wheat, whereas the Triplet×Oro cross combined two red winter wheats. Spring wheats, because of a shorter growing period and later summer maturity, commonly suffer more from high temperatures and drought than do winter wheats. The average kernel weight of the awned composite of Baart×Onas was 1.7 milligrams, or 4.3%, greater than that of the awnleted composite. The awned composite

TABLE 1.—*Kernel weights of composited awnleted and awned segregates.*

Station where grown	Weight per kernel, mgms									
	Awnleted composite					Awned composite				
	1936	1937	1938	1939	Av.	1936	1937	1938	1939	Av.
					Triplet × Oro					
Moro, Ore.	20.4	31.9	21.8	25.7	25.0	21.8	34.8	22.1	26.1	26.2
Pendleton, Ore	32.5	32.3	30.1	28.9	31.0	35.0	33.7	31.3	30.2	32.6
Union, Ore	—	—	34.6	33.8	34.2	—	—	34.2	35.6	34.9
Pullman, Wash	33.1	31.9	34.9	31.1	32.8	34.5	31.8	34.9	31.1	33.1
Walla Walla, Wash	32.6	—	33.4	34.6	33.5	33.4	—	33.2	34.9	33.8
Pomeroy, Wash.	24.2	—	21.8	28.7	24.9	24.3	—	22.4	29.7	25.5
Lind, Wash	—	—	27.8	27.7	27.8	—	—	28.6	28.0	28.3
Moscow, Idaho	—	35.2	34.4	—	34.8	—	37.1	33.7	—	35.4
Sandpoint, Idaho	—	37.3	31.3	34.3	34.3	—	39.8	31.7	36.2	35.9
Tetonia, Idaho.	—	34.5	31.3	30.8	32.2	—	39.7	32.2	30.2	34.0
Rockland, Idaho	—	—	28.6	24.2	26.4	—	—	28.8	27.1	28.0
Clarkston, Utah	—	—	39.7	27.9	33.8	—	—	35.1	31.2	33.2
Davis, Calif	—	—	38.7	33.0	35.9	—	—	38.8	31.9	35.4
Average	28.6	33.9	31.4	30.1	31.0	29.8	36.2	31.3	31.0	31.8
Times superior.	0	1	4	2	7*	5	5	8	9	27*
					Baart × Onas					
Moro, Ore.	18.0	35.2	26.5	25.7	26.4	20.6	39.6	28.5	27.4	29.0
Pendleton, Ore	39.0	42.1	40.0	38.6	39.9	38.9	46.1	40.3	39.8	41.3
Union, Ore.	—	45.5	42.7	—	44.1	—	41.9	45.8	—	43.9
Pullman, Wash	40.5	42.9	39.3	38.2	40.2	45.0	42.5	39.6	40.9	42.0
Walla Walla, Wash.	—	40.7	39.3	—	40.0	—	42.6	40.3	—	41.5
Pomeroy, Wash.	29.8	33.2	30.4	—	31.1	30.9	36.3	31.9	—	33.0
Lind, Wash	—	39.6	38.1	—	38.9	—	40.7	40.2	—	40.5
Moscow, Idaho	39.8	39.1	39.6	—	39.5	43.3	38.6	41.6	—	41.2
Sandpoint, Idaho	—	48.8	36.2	—	42.5	—	47.4	36.3	—	41.9
Tetonia, Idaho	—	37.8	—	—	37.8	—	43.3	—	—	43.3
Davis, Calif	—	—	45.0	35.5	40.3	—	—	48.2	35.6	41.9
Bozeman, Mont.†	35.0	50.4	43.1	—	42.8	35.6	51.7	45.2	—	44.2
Aberdeen, Idaho†	48.0	48.0	46.8	45.7	47.1	48.2	52.6	48.0	48.0	49.2
Logan, Utah†	—	—	38.6	41.6	40.1	—	—	39.8	43.6	41.7
Hesperus, Colo.†	—	49.6	40.5	—	45.1	—	50.8	43.2	—	47.0
Prosser, Wash.†	—	—	51.3	—	51.3	—	—	51.2	—	51.2
Tucson, Ariz.†	—	—	—	39.2	39.2	—	—	—	40.5	40.5
Average	35.7	42.5	39.8	37.8	39.6	37.5	44.2	41.3	39.4	41.3
Times superior	1	4	1	0	6*	6	9	14	7	36*

*Times superior for individual station years.
†Grown under irrigation.

had a greater kernel weight in 36 of the 42 tests. This distribution tested by the binomial method gives odds for a difference in favor of the awned composite greater than 99 to 1.

Data are not extensive enough to establish significant differences between the awned and awnleted composites at individual stations, but by grouping low rainfall stations such as Moro and Lind; intermediate rainfall stations such as Pendleton, Pullman, and Moscow; high rainfall stations such as Union; and irrigated stations and, also by combining results for the two hybrid populations, the number of tests is adequate for comparisons between different environments. These comparisons do not show any association in kernel weight between environment and awn type in the material.

EFFECT OF AWN ON TEST WEIGHT

Test weight, in pounds per bushel, is an important grain grading factor and also is associated with flour yield. It is influenced not only by kernel weight but also by kernel characters such as shape, size, plumpness, and density of the kernels, width, and depth of crease, and extent of brush. Despite the interest in this factor, no reference to its relation to awns has been found in the literature.

Comparative test weights of grain for 31 station years for the Triplet×Oro cross and for 35 station years for the Baart×Onas cross are shown in Table 2. In the Triplet×Oro cross the average difference in favor of the awned composite was 0.7 pound per bushel and in no case did the test weight of the awnleted composite exceed that of the awned composite. The weights were equal in only 3 of the 31 comparisons. In the Baart×Onas cross the average difference was 1 pound in favor of the awned composite and in only 3 of the 35 comparisons did the test weight of the awnleted composite equal or exceed that of the awned composite. A very positive advantage for awned types was obtained in both crosses and the differences were evident over the entire environmental range studied.

EFFECT OF AWN ON YIELD

Yields in bushels per acre for the awnleted and the awned composite from each of the two crosses are given in Table 3. The composites of the awnleted and the awned segregates from the Triplet×Oro cross averaged 39.4 and 39.2 bushels per acre, respectively, for the 48 station years. The awnleted composite gave the higher yield in 27 tests, the awned composite in 17 tests, and the yields were equal in 4 tests. Testing the distribution by the binomial method the odds are only 6 to 1 and the difference is not significant.

Yields of the awnleted and awned composites from the Baart× Onas cross were very similar in 1936 and 1937. In 1938, the awned composite gave the higher yield at each of the 15 stations, averaging 49.8 bushels compared to 43.1 bushels for the awnleted composite. In 1939, the awned composite gave the higher yield at six of the seven stations and averaged 47.9 bushels compared to 45.3 bushels for the awnleted composite. Considering the 50 station years, the awned composite was higher at 38 and averaged 45.8 bushels, whereas the awnleted composite was higher at only 11 and averaged 43.3 bushels. They were equal at one station one year. This distribution tested by the binomial method gives odds greater than 99 to 1 that the difference is significant.

TABLE 2.—*Test weights of composites of awnleted and awned segregates.*

Station where grown	Test weight in pounds per bushel											
	Awnleted composite						Awned composite					
	1935	1936	1937	1938	1939	Av.	1935	1936	1937	1938	1939	Av.
						Triplet × Oro						
Pullman	61.9	62.7	64.0	63.5	61.1	62.6	62.2	63.2	64.0	63.8	62.2	63.1
Walla Walla	60.4	61.0	—	60.6	60.5	60.6	60.8	61.7	—	61.3	61.2	61.3
Pomeroy	62.9	59.3	62.5	60.5	61.9	61.4	63.1	60.2	63.0	60.5	62.6	61.9
Lind	61.5	—	—	60.5	59.0	60.3	63.0	—	—	61.0	59.5	61.2
Moro	—	55.2	60.0	58.0	59.5	58.2	—	56.5	61.5	58.0	60.5	59.1
Pendleton	62.0	62.5	61.8	62.0	61.0	61.9	63.2	63.3	63.0	62.8	61.8	62.8
Moscow	62.0	—	—	61.9	62.0	62.0	62.4	—	—	62.2	62.2	62.3
Clarkston	—	—	—	62.0	—	62.0	—	—	—	62.9	—	62.9
Davis	—	—	—	—	61.7	61.7	—	—	—	—	62.3	62.3
Average	61.8	60.1	62.1	61.1	60.8	61.1	62.5	61.0	62.9	61.6	61.5	61.8
Times superior	0	0	0	1	0	1*	6	5	3	7	8	29*
						Baart × Onas						
Pendleton	—	60.0	61.7	61.1	—	60.9	—	61.2	62.3	62.2	—	61.9
Moro	—	46.5	58.0	54.5	54.0	53.3	—	50.0	59.0	56.0	56.0	55.3
Moscow	—	—	—	59.0	—	59.0	—	—	—	60.0	—	60.0
Davis	—	—	—	61.0	59.6	60.3	—	—	—	60.6	60.7	60.7
Pullman	—	62.0	59.7	61.9	61.3	61.2	—	63.1	61.0	62.1	62.0	62.1
Pomeroy	—	56.3	58.0	60.0	—	58.1	—	58.2	59.5	61.5	—	59.7
Walla Walla	—	61.0	60.0	61.7	—	60.9	—	62.5	61.0	62.3	—	61.9
Lind	—	56.0	—	59.5	—	57.8	—	57.0	—	60.0	—	58.5
Aberdeen†	—	57.2	61.2	60.0	—	59.5	—	57.7	62.0	61.5	—	60.4
Logan†	—	60.5	60.5	62.0	60.0	60.8	—	61.5	59.0	62.5	60.5	60.9
Bozeman†	—	60.2	62.0	64 5	—	62.2	—	60.8	62.5	65.8	—	63.0
Prosser†	—	—	—	61.7	—	61.7	—	—	—	62.7	—	62.7
Hesperus†	—	—	—	61.0	—	61.0	—	—	—	60.0	—	60.0
Mesa†	—	—	—	—	60.5	60.5	—	—	—	—	63.0	63.0
Average	—	57.7	60.1	60.6	59.1	59.5	—	59.1	60.8	61.3	60.4	60.5
Times superior	—	0	1	2	0	3*	—	9	7	11	5	32*

*Times superior for individual station years.
†Grown under irrigation.

The average number of heads per row of the Baart×Onas cross at seven stations in 1936 and nine stations in 1937 was 455 for the awnleted composite and 460 for the awned composite. This difference is not significant. While the number of heads per row was not recorded in 1938 and 1939 (except at Pullman, Wash., in 1939), there were no observable differences between the awnleted and awned composites in stand, date of heading, plant height, etc. At Pullman in 1939 there was an average of 408 heads per row in the awnleted composite and 421 heads in the awned composite. This difference is not significant, although the difference in yield was 4.0 bushels per acre.

TABLE 3.—*Yield of composites of awnleted and awned segregates.*

Station where grown	Yield in bushels per acre											
	Awnleted composite						Awned composite					
	1935	1936	1937	1938	1939	Av.	1935	1936	1937	1938	1939	Av.
	Triplet × Oro											
Pullman	85.8	53.8	78.2	75.7	67.0	72.1	87.8	51.0	80.7	72.2	64.0	71.1
Walla Walla	43.7	50.8	—	40.2	51.7	46.6	42.2	52.7	—	40.0	51.3	46.6
Pomeroy	52.7	36.5	33.0	26.5	31.0	35.9	61.7	36.5	30.7	27.2	36.0	38.4
Lind	25.2	—	—	17.9	13.2	18.8	23.3	—	—	17.6	13.1	18.0
Pendleton	34.9	32.1	34.1	46.8	37.2	37.0	33.4	34.4	34.2	44.2	37.7	36.8
Moro	9.1	15.5	26.3	22.2	24.4	19.5	7.9	17.3	23.3	21.4	26.2	19.2
Union	54.3	53.0	—	56.2	55.3	54.7	48.9	51.3	—	52.4	48.2	50.2
Moscow	24.6	—	61.1	57.5	52.3	48.9	38.3	—	56.3	57.5	58.0	52.5
Tetonia	25.3	18.5	30.3	37.1	23.6	27.0	22.7	18.5	25.3	33.2	23.7	24.7
Sandpoint	35.7	—	51.4	54.2	44.3	46.4	32.5	—	59.1	54.8	41.3	46.9
Rockland	22.9	8.2	—	—	—	15.6	22.8	7.9	—	—	—	15.4
Clarkston	—	—	21.0	37.7	—	29.4	—	—	25.0	37.7	—	31.4
Average	37.7	33.6	41.9	42.9	40.0	39.4	38.3	33.7	41.8	41.7	40.0	39.2
Times superior	8	4	4	8	5	29*	3	4	4	3	5	19*
	Baart × Onas											
Pendleton	—	37.2	37.4	40.9	35.1	37.7	—	42.1	38.7	44.8	42.0	41.9
Moro	—	13.1	19.9	23.8	17.2	18.5	—	15.6	25.5	25.2	18.4	21.2
Union	—	49.2	57.0	52.3	—	52.8	—	50.6	53.7	52.8	—	52.4
Moscow	—	38.8	54.4	36.4	—	43.2	—	38.8	50.5	37.8	—	42.4
Tetonia	—	20.3	34.7	32.4	—	29.1	—	18.0	34.8	33.6	—	28.8
Sandpoint	—	31.9	31.5	—	—	31.7	—	33.8	27.0	—	—	30.4
Pullman	—	57.3	59.8	45.7	40.5	50.8	—	61.3	61.8	50.5	44.5	54.5
Pomeroy	—	27.3	28.0	27.3	—	27.5	—	28.0	28.5	29.7	—	28.7
Walla Walla	—	45.3	24.8	45.3	—	38.5	—	46.8	27.3	50.2	—	41.4
Lind	—	15.3	15.2	17.8	—	16.1	—	13.5	15.1	28.4	—	19.0
Davis	—	—	—	47.0	36.6	41.8	—	—	—	48.3	39.9	44.1
Aberdeen†	—	76.9	75.4	76.6	59.4	72.1	—	77.0	75.7	78.7	61.4	73.2
Logan†	—	72.7	44.2	59.8	69.0	61.4	—	69.2	52.3	76.6	78.5	69.2
Bozeman†	—	38.7	64.9	37.0	—	46.9	—	43.3	62.7	49.0	—	51.7
Prosser†	—	—	—	57.6	—	57.6	—	—	—	78.5	—	78.5
Hesperus†	—	56.1	74.5	45.9	—	58.8	—	47.0	69.8	63.0	—	59.9
Mesa†	—	—	—	—	59.0	59.0	—	—	—	—	50.4	50.4
Average	—	41.4	44.4	43.1	45.3	43.3	—	41.8	44.5	49.8	47.9	45.8
Times superior	—	4	6	0	1	11*	—	9	8	15	6	38*

*Times superior for individual station years.
†Grown under irrigation.

SUMMARY

Composited populations of homozygous awnless or awnleted and of awned plant segregates from two wheat crosses, Triplet×Oro and Baart×Onas, were grown in adjacent replicated nursery plots in 5 and 4 years, respectively, at several widely distributed western experi-

ment stations. The grain from the composite of awned plants was superior to that from the composite of awnless or awnleted plants in both kernel weight and test weight per bushel for each cross regardless of environment. Yields of the two composites from the winter wheat cross, Triplet×Oro, were not significantly different, but in the spring wheat cross, Baart×Onas, the awned composite yielded significantly more than the awnless or awnleted composite in 2 of the 4 years.

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THE EFFECT OF CALCIUM AND POTASSIUM FERTILIZERS ON THE SOLIDITY AND THE CALCIUM AND POTASSIUM CONTENT OF CANNED TOMATOES[1]

C. B. SAYRE, Z. I. KERTESZ, AND J. D. LOCONTI[2]

FIRMNESS or solidity of tomatoes is of great importance in the quality of the canned product. A method developed at the New York State Agricultural Experiment Station for the treatment of tomatoes with soluble calcium salts (2)[3] during processing greatly increased the firmness of the canned product. Minute quantities of calcium taken up by the tissues by this method have definitely improved the solidity and increased the drained weight and firmness of the tomatoes.

The objects of the experiment reported here were two-fold. First, to find out if the application of calcium salts as an amendment to the soil in which tomatoes were grown would increase the uptake of calcium by the plant and result in an increase in the calcium content and firmness of the tomato fruit. It has been reported (1) that with an abundant supply of potassium there is some replacement of calcium by potassium in the plant. The second object was to test the effect of increasing amounts of potassium fertilizers on the firmness of the fruit and, particularly, to determine if increased potassium fertilizers would reduce the calcium content of the tomatoes.

EXPERIMENTAL METHODS

Nystate tomatoes were used throughout these experiments. They were grown on the Canning Crops Investigations Farm of the Experiment Station on 1/40th acre plats with all treatments replicated three times in randomized arrangement. The kind and amount of fertilizer applied to the various plats is shown in Table 1.

Only No. 1 tomatoes, graded at the farm, were delivered for canning. The fruit in the first set of samples, harvested on September 2, were ripe and fairly soft. At the time of the experiment this was attributed to the holding of the fruit in storage overnight prior to canning. Later tests showed, however, that holding tomatoes overnight in storage had little effect on the firmness of the canned product. The tomatoes from each lot were handled separately in a commercial cannery. They were washed, steamed, peeled, cored, and packed by hand in No. 2½ size cans[4] in the first series (September 2) and in No. 2 size cans in the second series (September 11 and 12). The weight of tomatoes put into each can was noted on the outside of the can to allow a precise calculation of the "drained weight" in relation to the "put in weight". No salt was added to the first lot, but 35-grain

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[3]Figures in parenthesis refer to "Literature Cited", p. 394.

[4]The authors are indebted to the Research Department of the American Can Company for assistance in the canning of the tomato samples, and to the Geneva Preserving Company for the use of their factory for canning the several lots of tomatoes.

salt tablets were added to the cans of the second series. The cans were filled with tomato juice from the respective lot of tomatoes and closed cold by a Canco 006 vacuum closing machine. The No. 2 and No. 2½ size cans were processed for 55 and 60 minutes, respectively, in boiling water.

The samples were opened for observation after two months' storage. The method described by the Bureau of Agricultural Economics, U. S. Dept. of Agriculture, was used to determine the drained weight. The drained tomato meat was subsequently analyzed for calcium and potassium, using the official methods. To avoid the very confusing effect of the unavoidable variation in the "put in weight", the amount of tomato solids which stayed on the screen was expressed as the percentage of the weight of tomatoes placed in the can.

EXPERIMENTAL RESULTS AND DISCUSSION

The results of the "drained weight" analyses are presented in Table 1. It appears from an examination of these data that the differences in the drained weight content of the samples did not exceed the variation usually observed in individual cans of tomatoes prepared from the same lot of fruit. The percentage of "drained weight" in all samples was between 63.2 and 77.0% of the "put in weight". Recent work at this Experiment Station (3) showed that the addition of small quantities (0.07%) of calcium chloride to the can or dipping the fruit into a 1% solution of calcium chloride solution for 1 minute is in all cases sufficient to increase the drained weight of the tomatoes to over 80% of the "put in weight". Nothing approaching such an effect could be observed in the present samples showing that neither the calcium nor the potassium used as a fertilizer had any significant influence on the firmness of the canned fruit.

In order to affect the firmness in a manner similar to the treatment of the tomato fruit before or during preservation, the calcium supplied as fertilizer would have to find its way into the fruit through the plant. The fact that the calcium content of tomatoes is only insignificantly, if at all, influenced by calcium supplied in the fertilizer is well demonstrated in Table 2. Although occasionally the calcium content of the tomatoes from some plats was slightly higher than that usually found in fruit grown under commercial conditions, this slightly increased calcium content could not be associated with any consistent increase in the drained weight in the canned samples.

Table 2 also shows that the tomatoes did not take up any significant amount of potassium from that provided in the fertilizers. Tomatoes were analyzed for potassium from a plat receiving the highest amount of potassium (600 pounds 5-20-20; No. 2 Tables 1 and 2), from a plat receiving no potassium (600 pounds 5-20-0; No. 1, Table 2), from a plat receiving a small amount of potassium (600 pounds 5-20-5; No. 3, Table 2), and from a plat receiving this same amount at planting time plus a late side dressing of an equal amount of nitrogen and potash. Since these extreme differences in amount of potash fertilizer used resulted in no significant differences in the percentage of potassium found in the tomatoes, it was not considered worthwhile to analyze the entire series of tomatoes for potassium.

TABLE 1.—*Fertilizers applied and results of determinations of "drained weight" in experimentally canned whole tomatoes.*

Plat No.	Treatment*	Average "drained weight" as percentage of "put in weight"† 1st series	2nd series	Average of all samples	Yield per acre, tons
1	600 lbs. 5–20–0 drilled	74.8	69.5	72.2	9.18
2	600 lbs. 5–20–20 drilled	71.8	75.4	73.6	11.09
3	600 lbs. 5–20–5 drilled	69.9	76.4	73.2	9.86
4	100 lbs. sulfur (300 mesh) broadcast + 250 lbs. Ammo Phos 11–48 drilled	72.8	64.3	68.6	8.87
5	200 lbs. sulfur (300 mesh) broadcast + 600 lbs. 5–20–5 drilled	69.2	63.2	66.2	8.96
6	20 lbs. borax, 150 lbs. $MnSO_4$ and 250 lbs. $MgSO_4$ broadcast + 600 lbs. 5–20–5 drilled	68.7	77.0	72.8	8.47
7	1000 lbs. $CaCl_2$ broadcast + 600 lbs. 5–20–0 drilled	72.7	65.8	69.2	7.31
8	20 lbs. borax, broadcast + 600 lbs. 5–20–5 drilled	71.7	71.8	71.8	10.06
9	250 lbs. Ammo Phos 11–48 drilled	72.7	65.6	69.1	9.02
10	600 lbs. 5–20–5 drilled + NK side dressing later. July 25	73.6	70.1	71.9	9.89
11	600 lbs. 5–20–0 drilled + 500 lbs. $CaCl_2$ late side dress	68.3	66.1	67.2	8.51
12	250 lbs. Ammo Phos 11–48 drilled + 500 lbs. calcium chloride broadcast	—	71.8	71.8	8.23
13	1200 lbs. gypsum broadcast + 600 lbs. 5–20–5 drilled	73.9	71.7	72.8	9.87

*Broadcast treatments applied May 20 and disced in Drill treatments applied May 31 and not disturbed. Tomatoes transplanted June 1, 3 rows per plat; rows 5 feet apart; plants 3 feet in row. The superphosphate used contained about 50% $CaSO_4$. In order to obtain fertilizer free from calcium, the P_2O_5 in plats 4, 9 and 12 was supplied in the form of commercial ammonium phosphate (Ammo Ps 11–48 containing 11% N and 48% P_2O_5).

†Averages obtained from two or three samples.

TABLE 2.—*Results of chemical analyses of tomatoes, 1939.*

No. Plat	1st harvest canned		2nd harvest canned		
	Dry matter, %	Calcium, %	Dry matter, %	Calcium, %	Potassium (as K_2O), %
1	6.32	0.0057	5.78	0.0050	0.312
2	6.10	0.0059	5.61	0.0044	0.343
3	6.57	0.0067	6.31	0.0056	0.324
4	6.70	0.0066	6.23	0.0055	—*
5	6.68	0.0141	6.70	0.0044	—*
6	6.43	0.0164	6.57	0.0046	—*
7	6.50	0.0081	6.88	0.0046	—*
8	6.75	0.0065	6.80	0.0054	—*
9	6.23	0.0115	6.72	0.0059	—*
10	6.58	0.0066	7.47	0.0049	0.312
11	6.70	0.0078	6.50	0.0090	—*
12	—*	—*	7.01	0.0047	—*
13	6.82	0.0146	7.02	0.0053	—*

*Not analyzed.

The differences in the potassium content of the samples analyzed are well within the natural variation; but in view of the generally accepted antagonistic effect of calcium and potassium, it is doubtful whether potassium reaching the fruit could increase its firmness. It has been shown (1, 5) that more potassium will cause a lower uptake of calcium. It is not quite certain that the effect of the natural calcium content on firmness is similar to that of the calcium salts used in producing the "calcium effect" in processing. But if it is so, then any improvement caused by the potassium would have to be great enough also to counteract the lowered solidity caused by the diminished calcium content of the tissues.

The soil on which these tomatoes were grown is classified as Ontario silt loam. The pH of the soil is 7.3. There are many small fragments of limestone scattered through this soil. There is no evidence that calcium is a limiting factor in plant growth. The abundant supply of calcium may explain why the liberal application of calcium salts as soil amendments did not significantly affect the calcium content of the tomatoes (Table 2) grown on this soil. In order not to change the pH of the soil, two neutral salts of calcium ($CaCl_2$ and $CaSO_4$) were used in certain field treatments (Nos. 7, 11, 12, and 13) in this test. The calcium chloride is very readily water-soluble and on account of its deliquescent character very quickly dissolved in the soil. The gypsum, though less soluble, supplies calcium to the plant in a very readily available form.

All of the fertilizer treatments carrying superphosphate also contained gypsum. Therefore, only in treatments 4 and 9, in which the phosphorus was supplied in Ammo Phos, was there no calcium salt applied in the fertilizer treatment. In treatment 12 the same amount of Ammo Phos was used as in treatment 9, but in No. 12 an active calcium salt (500 pounds $CaCl_2$) was also added. It is interesting to note in Table 2 that the tomatoes from treatment 9, in which no calcium salt was used, showed a higher calcium content than the

tomatoes from treatment 12 in which 500 pounds per acre of $CaCl_2$ had been applied. Evidently the tomatoes were abundantly supplied with calcium in this soil.

In treatments 4 and 5, respectively, 100 pounds and 200 pounds of very finely ground sulfur were applied. This would have a slightly acidifying effect on the soil, particularly the heavier application and would have a tendency to make the potassium more available to the plants by delaying the rate of fixation of potash in the soil. This might result in a greater uptake of potassium by the plants and a corresponding replacement of calcium, but Table 2 shows that it did not affect the calcium content of the tomato fruits.

Previous experiments on this soil (4) had shown that a lack of available phosphorus was the principal fertilizer factor limiting yields of tomatoes, and that only when liberal amounts of phosphorus and nitrogen fertilizers were also applied would potash fertilizers increase the yield of tomatoes. For that reason nitrogen and phosphorus fertilizers were applied uniformly to all the treatments in this experiment.

Treatment No. 1 (600 pounds 5–20–0) compared with treatment No. 3 (600 pounds 5–20–5) and with treatment No. 2 (600 pounds of 5–20–20) furnishes a direct comparison of increasing amounts of potassium fertilizer with the nitrogen and phosphorus fertilizers identical in all of these treatments. It should be noted in Table 2 that the heaviest application of potash fertilizer, treatment 2 in which 120 pounds of K_2O were applied, did not significantly increase the potassium content nor decrease the calcium content of the ripe tomatoes as compared with treatment 1 in which no potash was used. Furthermore, treatment No. 10 (600 pounds of 5–20–5+sulfate of ammonia and muriate of potash as a side dressing to supply an additional 30 pounds of nitrogen and 30 pounds of K_2O per acre) also did not increase the potassium content of the tomatoes at all, nor did it have any appreciable effect on the calcium content of the fruit.

The yield records show that the soil did not supply potassium to the plant in sufficient amounts for maximum growth. The largest yield was obtained from treatment 2 which supplied the largest amount of potash (600 pounds 10–20–20). Increased yields were obtained from treatments 2, 3, 10, and 13, all of which supplied potash, as compared with treatments 1, 4, 7, 9, 11, and 12 in which no potash was used in the fertilizer application. These fertilizer treatments in which sufficient potash was supplied to increase the yields of the tomatoes did not, however, have an appreciable effect in increasing the potassium content nor decreasing the calcium content of the fruit.

CONCLUSIONS

On a soil in which calcium is naturally abundantly supplied and in which potassium is not adequately supplied for maximum crop yields, the addition of calcium salts or potassium salts as soil amendments in the amounts used in this experiment had no appreciable effect on the calcium or potassium content of tomatoes grown on the soil, nor on the firmness of the canned tomatoes as measured by the drained weight.

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AN IMPROVEMENT IN LYSIMETER DESIGN[1]

Ellis F. Wallihan[2]

THE use of lysimeters for the study of moisture and nutrient losses from soils by drainage has been widespread. In many cases information of a fundamental nature has been sought and a great deal of reliance placed on the results of lysimeter studies.

The most common lysimeter installation consists of a column of soil which has been isolated from the surrounding soil either by removal to a new location and placing in tanks or by building a wall around a portion of soil in place. In either case, the soil in the lysimeter is disconnected from the surrounding natural body of soil. This discontinuity results in abnormal soil moisture conditions within the lysimeter.

In spite of the fact that soil physicists have realized for some time that moisture conditions in lysimeters are often not comparable with those of the natural soil in place, there have been reported relatively few attempts to determine the nature and degree of the differences. Neal, Richards, and Russell[3] showed that the soil in the bottom of a lysimeter must be nearly saturated with water before drainage will occur. This fact may be explained as follows: In a soil containing an amount of moisture less than that required for saturation, the water is under capillary tension. The magnitude of this tension bears an inverse, though not linear, relation to the moisture content of the soil. Thus there is an energy gradient (due to capillary forces) tending to hold the water in the soil. In order to effect a removal of any portion of this water, it is necessary that an opposing energy gradient of greater magnitude than the existing one be applied. For example, in a lysimeter which is drained by gravity (a relatively constant energy gradient which tends to remove water from soil) it is apparent that water will drain from the soil only as long as the energy gradient due to capillary forces in the soil has a lower value than that of the opposing force, gravity.

The question arises, then, as to what is the capillary tension in the bottom of a soil column which just balances the force of gravity. In the work of Neal, Richards and Russell, referred to above, drainage failed to occur even when the capillary tension dropped to a value equivalent to a 1 cm of mercury column. In the work reported in the present paper drainage occurred when the capillary tension was about 2 cm of mercury. The exact value might be expected to vary somewhat with the lysimeter design and type of soil being used. In any case, it appears that a soil must be nearly saturated with water before drainage will be effected by the force of gravity only.

In contrast to the condition in lysimeters is that of a deep, well-drained soil in which the water table is at a considerable distance

[1]Contribution from the Department of Forestry, Cornell University, Ithaca, N. Y. Received for publication March 18, 1940.

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[3]NEAL, O. R., RICHARDS, L. A., and RUSSELL, M. B. Observations on moisture conditions in lysimeters. Soil Sci. Soc. of Amer. Proc., 2:35–44. 1937.

below the surface. In this case the energy gradient due to gravity tending to move water downward through the soil mass is supplemented by the energy gradient resulting from the capillary tension in the soil below. Therefore, to an extent depending on the magnitude of this latter energy gradient, the downward movement of water from a given portion of soil will occur at higher capillary tensions in a natural body of soil than in the soil at the bottom of a lysimeter. The result is a higher moisture content in lysimeter soils than in similar soils in place.

As stated above, this discussion applies to well-drained soils. To the extent that drainage is impeded in soils by impervious layers, the moisture conditions in lysimeters may tend to approach the natural conditions.

On the basis of these considerations, it might be expected that conclusions drawn from lysimeter studies would not be applicable in all cases to field conditions. Some of the possible effects of the abnormal moisture conditions in lysimeters would be (1) more rapid evaporation of moisture from the soil surface resulting in reduced volume of percolate, (2) inhibition of nitrification and possibly the occurrence of nitrate reduction due to restricted aeration at the bottom of the soil column, and (3) attendant changes in chemical composition of the soil solution. Furthermore, since the volume of water retained in a given mass of soil might be greater in a lysimeter than in a natural soil, there would be in such cases more water available to plants grown on the soil.

The purpose of this paper is to report a study in which an attempt was made to correct the error, which heretofore has been inherent in lysimeter studies, by applying an artificial capillary tension in the bottom of the lysimeter. This was done by placing a tensiometer cup near the bottom of the soil mass and withdrawing soil water with controlled vacuum. It should be recognized that the work was exploratory in nature and there was not sufficient replication of conditions to permit exact quantitative conclusions. Rather it was proposed to determine (1) whether or not this method is a practical one for correcting the moisture conditions in lysimeters and (2) the general trend of results obtained as compared with those from the usual type of lysimeter.

MATERIALS AND METHODS

The four lysimeters used consisted of Pyrex glass cylinders[4] 12 inches in diameter and 30 inches deep with round bottoms. There was a 1-inch hole in the bottom of each cylinder. The open end of a tensiometer cup was inserted in this hole in the inverted position, thus leaving the porus wall of the cup inside the lysimeter to be in contact with the soil and the open end extending below the bottom of the cylinder. Thus the water could be allowed to drain through the tensiometer cup by gravity or be removed by vacuum applied to it. For the measurement of soil moisture conditions in the lysimeters, two tensiometers[5] were placed in each, one

[4]The author is indebted to the Department of Agronomy for the loan of these cylinders.

[5]For a discussion of tensiometers see Wallihan, E. F. Use of tensiometers for soil moisture measurement in ecological research. Ecology, 20:403–412. 1939.

about an inch from the bottom and the other 6 inches below the surface of the soil. A diagram of the complete assembly is shown in Fig. 1.

The soil used was a Dunkirk fine sandy loam obtained from a woodlot of mixed hardwoods near Ithaca, N. Y. Soils from the A_1 and C horizons were used separately, i.e., the bottom 21 inches of each lysimeter were filled with soil from the C horizon and a layer of A_1 horizon 6 inches thick placed on top of this. Each of the two lots of soil was thoroughly mixed and passed through a half-inch mesh screen prior to filling the lysimeters. Successive buckets full were placed in various lysimeters to create as great uniformity as possible. The soil was packed slightly by hand to prevent the occurrence of large channels through which water might flow. Each lysimeter was wrapped with building paper to prevent abnormal growth of algae next to the glass cylinder wall. To prevent serious disturbance of the soil when water was added, 15 grams of sugar maple leaves were spread over the surface of the soil in each lysimeter. Distilled water only was used, with equal amounts added to each lysimeter. Percolates were collected at irregular intervals.

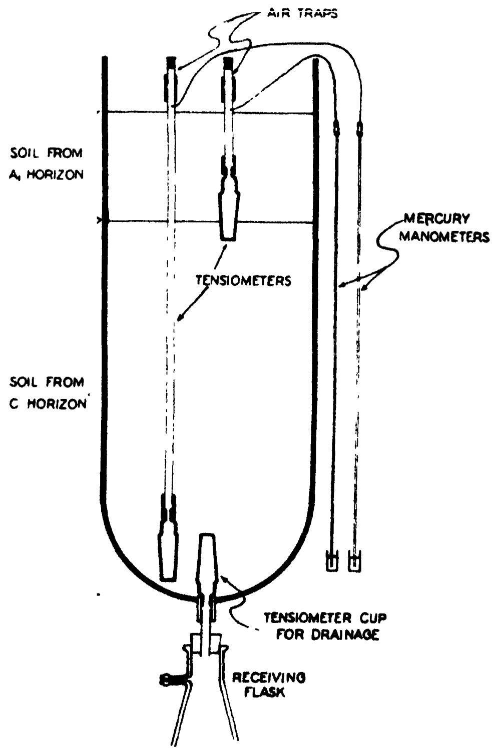

FIG. 1.—Diagram of the complete assembly of the lysimeters.

The plants grown during the second part of the experiment were oats. Twenty seeds were sown on each of two of the lysimeters and 19 plants resulted in each case.

Chemical tests were made as follows: Total nitrogen determinations were run on the harvested tops of the oat plants by the semi-micro Kjeldahl method, modified to include nitrate nitrogen. In the lysimeter percolates nitrate nitrogen was estimated by the phenol-disulphonic acid method and calcium by precipitation with oxalic acid and ammonia and titration with potassium permanganate. There was no replication of chemical determinations.

PROCEDURE

At the outset of the experiment 7 liters of water were added to each lysimeter and the excess removed from the bottom with a tension equivalent to 20 cm of mercury. After 12 days the moisture conditions in the four lysimeters were similar, as indicated by the tensiometer readings. At that time the vacuum was released

from lysimeters II and III, thus permitting them to drain freely, and a tension of approximately 10 cm of mercury was applied continuously thereafter to numbers I and IV. Irrigations were applied at irregular intervals. Over a period of two months the total water applied was 8.16 surface inches. During this period the tensiometers were read daily, with few exceptions. Early in the tests the deeper tensiometer in lysimeter II ceased functioning so no data are available for the moisture conditions at that position.

The data from this test make possible a comparison of the conventional type of lysimeter with that in which the drainage water is removed by suction, both in the fallow condition. It was desired to determine also their behavior when plants were grown in the soils. Oat seeds were therefore sown on lysimeters III and IV and allowed to grow until the plants were about 15 inches tall. Irrigation was discontinued early in their growth period to simulate a natural period of drought. The tops were harvested when the plants on lysimeter IV began to wilt. They were dried at a temperature of 70° C and weighed.

After the plants were harvested irrigation was resumed and continued until drainage occurred from all the lysimeters. The purpose of this treatment was to obtain final percolates from which could be determined the effect of the plants on the composition of the soil solution.

RESULTS

The tensiometer readings are shown graphically in Fig. 2. For lysimeters I, III, and IV the tensions reported represent conditions at the bottoms of the lysimeters. As mentioned above, comparable readings were not available for number II and the capillary tensions at the 6-inch depth in the soil are reported. However, these probably do not differ markedly from the values at the bottom of the soil column, as indicated by comparison of readings from the two tensiometers in lysimeter III which differed by only 1 to 2 cm of mercury column. Since lysimeters II and III were treated alike in the early part of the experiment, this comparison is feasible. The irrigations are charted at the bottom of Fig. 2 in surface inches. The duration of the experiment is divided into two phases, *viz.*, tests made while the soils were (1) all fallow, and (2) under crop in lysimeters III and IV.

In Fig. 3 are plotted the cumulative volume of percolate from each lysimeter and the cumulative volume of water added to the surface of each.

The volumes of the various portions of percolate are given also in Table 1. Incorporated in this table are the concentrations of nitrates and calcium in the percolates as well as the total amounts of these ions removed in each portion of percolate.

The data for the oat plants grown in lysimeters III and IV are given in Table 2.

DISCUSSION

In the tensiometer curves shown in Fig. 2, a comparison of lysimeters I and IV with II and III shows that the removal of drainage water by controlled suction (I and IV) was effective in preventing the waterlogged condition which occurred in the soils drained only by gravity (II and III). The volumes of percolate, given in Table 1,

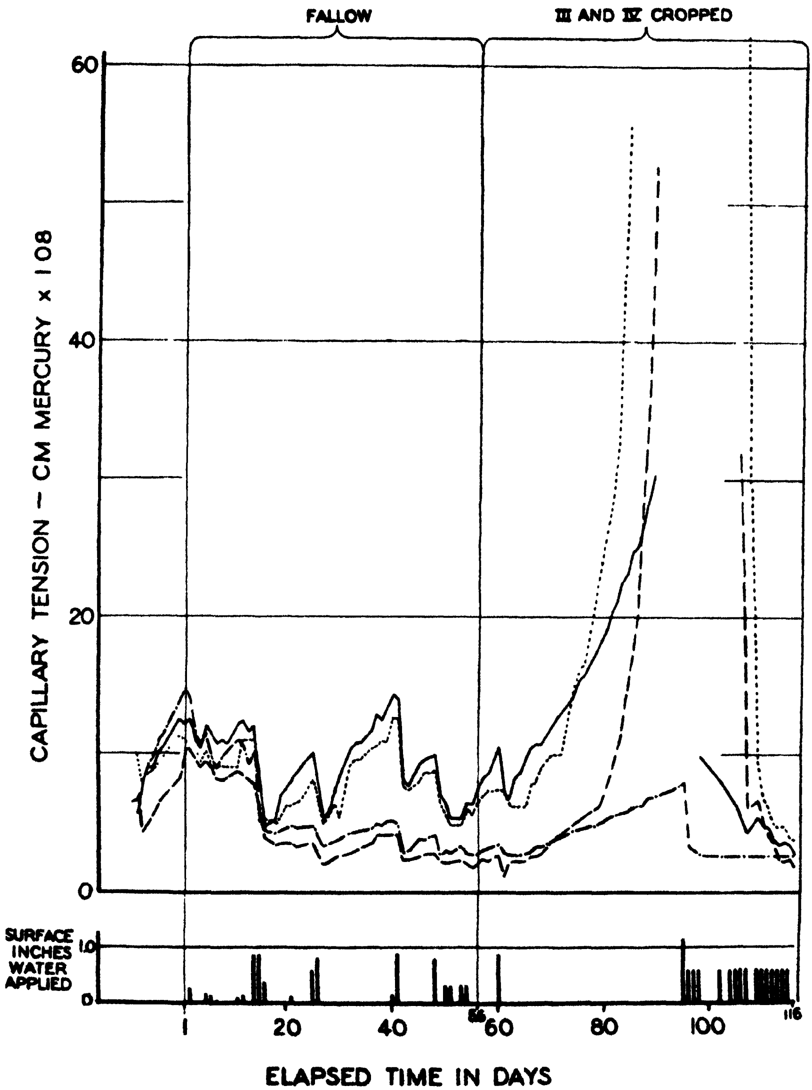

FIG. 2.—Capillary tension records from the lysimeters.

————————	Lysimeter I bottom
—— · —— · —— · ——	" II 6 inch depth
—— —— —— ——	" III bottom
· · · · · · · · · · · ·	" IV bottom

I and IV with tension; II and III without tension.

were about three times as great from I and IV as from II and III up to the time the oat seedlings became established. Comparison of I with II at the end of the experiment, since these had no plants grow-

TABLE 1.—*Volumes of lysimeter percolates, concentrations, and amounts of nitrates and calcium.*

Elapsed time in days	Volume of percolate, cc				Concentration of nitrates, P.P.M.				Concentration of calcium, P.P.M.				Total nitrates, mg				Total calcium, mg			
	I*	II*	III*	IV*	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
									All Lysimeters Fallow											
Initial wetting	895	730	368	187	30	33	33	36	24	24	23	26	27	24	12	7	21	17	8	5
	562	745	562	414	40	37	48	45	26	28	28	—	23	28	27	19	15	21	16	—
Total	1,457	1,475	930	601									50	52	39	26	36	38	24	5
5	54	—	—	60	56	—	—	56	36	—	—	37	3	—	—	3	2	—	—	2
9	130	—	—	155	69	—	—	77	31	—	—	35	9	—	—	12	4	—	—	5
14	50	—	—	60	74	—	—	87	34	—	—	40	4	—	—	5	2	—	—	2
16	357	—	—	430	118	—	—	105	49	—	—	42	42	—	—	45	17	—	—	18
17	438	—	—	530	125	—	—	111	48	—	—	44	55	—	—	59	21	—	—	23
18	290	—	—	200	100	—	—	100	50	—	—	44	29	—	—	20	14	—	—	9
19	360	—	—	95	125	—	—	100	49	—	—	47	45	—	—	10	18	—	—	4
20	245	—	—	285	100	—	—	95	47	—	—	45	25	—	—	27	12	—	—	13
25	565	—	—	525	136	—	—	124	48	—	—	49	77	—	—	65	27	—	—	26
26	165	—	—	240	140	—	—	145	50	—	—	51	23	—	—	35	8	—	—	12
28	550	140	200	680	157	122	106	122	52	45	47	52	86	17	21	97	29	6	9	35
33	760	133	83	955	174	134	131	167	56	46	49	54	132	18	11	160	43	6	4	52
46	325	280	115	370	245	170	170	245	65	52	55	65	80	48	20	91	21	15	6	24
53	—	465	330	—	—	188	222	—	—	54	58	—	—	87	73	—	—	25	19	—
56	910	315	240	920	286	231	240	333	76	55	62	72	260	73	58	306	69	17	15	66
Totals	5,199	1,333	968	5,505									870	243	183	935	287	69	53	291
Means†					167	182	189	170	55	52	55	53								

Oats Grown in Lysimeters III and IV

63	1,150	390	485	1,080	490	200	227	246	88	58	65	76	564	78	110	266	102	23	32	82
76	240	—	—	280	336	—	—	294	94	—	—	80	81	—	—	82	23	—	—	22
105	1,010	790	—	—	336	200	—	—	86	55	—	—	340	158	—	—	56	43	—	—
107	990	—	—	—	400	—	—	—	103	—	—	—	396	—	—	—	102	—	—	—
109	1,020	900	—	—	400	173	—	—	97	51	—	—	408	156	—	—	99	46	—	—
111	1,050	—	—	—	346	—	—	—	82	—	—	—	363	—	—	—	86	—	—	—
113	970	1,110	—	—	240	168	—	—	67	49	—	—	233	185	—	—	65	54	—	—
114	—	—	—	1,100	—	—	—	24	—	—	—	23	—	—	—	27	—	—	—	25
115	1,000	—	—	—	208	—	—	—	56	—	—	—	208	—	—	—	56	—	—	—
116	775	810	1,100	—	205	160	22	—	55	49	21	—	159	130	24	—	43	40	23	—
117	—	155	—	1,015	—	155	—	44	—	53	—	28	—	24	—	44	—	8	—	28
Totals	8,205	4,145	1,585	3,475									2.752	731	134	419	632	214	55	157
Means†					335	176	84	121	77	52	35	45								
Grand totals	14,861	6,953	3,483	9,581									3.672	1,026	356	1,380	955	321	132	453

*Lysimeters I and IV with tension; lysimeters II and III without tension.
†Means calculated from totals.

ing on them, shows the same relationship. This is due, in part, to the fact that all the lysimeters had approximately equal moisture contents at the beginning of the experiment, but during the remainder

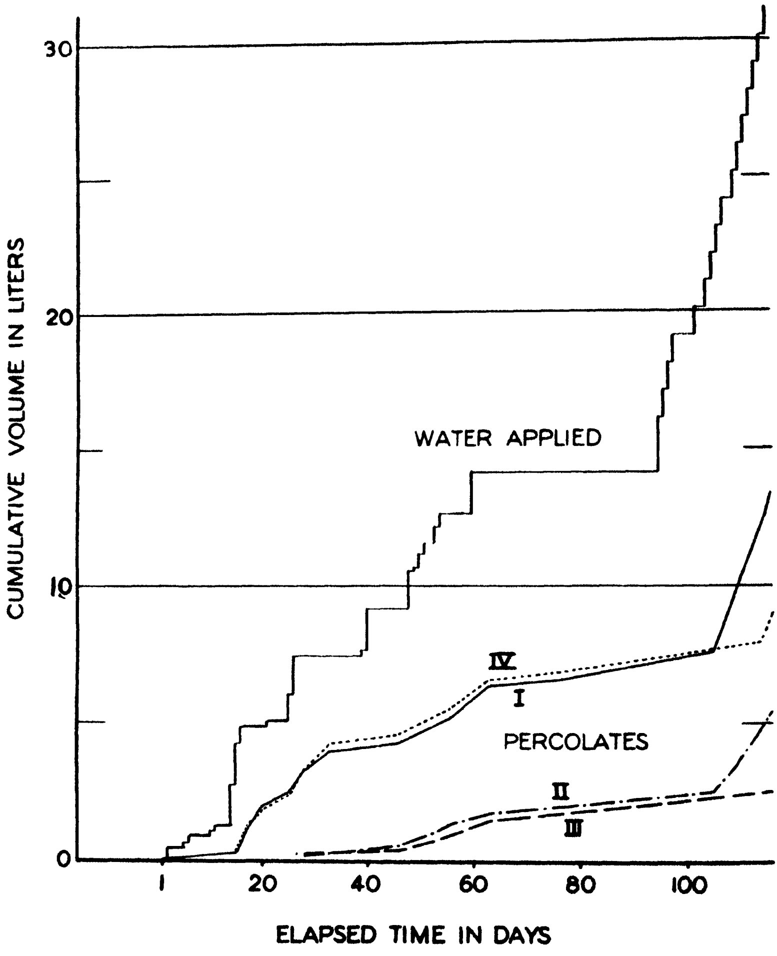

FIG. 3.—Cumulative volumes of water applied to and percolates from lysimeters.

———————————	Lysimeter I
—— · —— · —— · ——	" II
—— —— —— —— ——	" III
· · · · · · · · · · · ·	" IV

I and IV with tension; II and III without tension.

of the time a larger portion of the added water was retained by the soils in II and III than in I and IV. However, there is evidence that the rate of evaporation from lysimeters II and III was greater than

that from I and IV. Reference to Fig. 2 shows that on the fifty-third day of the experiment the capillary tension, and therefore the percentage of moisture, in each lysimeter was almost exactly the same as it was on the twenty-seventh day. Since equal amounts of water were added to each of the lysimeters, the volumes of percolates should have been equal if the rates of evaporation from the surface of the soil were the same. As a matter of fact, 1,635, 1,018, 728, and 2,005 cc of solution percolated from lysimeters I, II, III, and IV, respectively, during this period. One may conclude, therefore, that evaporation of water was most rapid from the lysimeters having higher moisture contents.

TABLE 2.—*Dry weights and nitrogen contents of tops of oat plants.*

Lysimeter No.	Dry weight of tops, grams	Total nitrogen	
		%	Grams
III (without tension)	21.0	2.78	0.584
IV (with tension)	11.8	3.02	0.536

Analyses of the percolates, reported also in Table 1, show that the concentrations of nitrate nitrogen and calcium in the soil solutions were greater in lysimeters I and IV than in those which were drained by gravity only. The differences in total amounts of these elements in the drainage waters were even greater. The low rate of nitrate accumulation in the poorly drained lysimeters can be explained, as suggested above, on the basis of the limited accessibility of oyxgen. The low calcium concentration is probably due largely, in turn, to the low anion concentration.

The relative dry weights of the oat plants produced on lysimeters III and IV appears to be important in spite of the fact that no replication of conditions was employed. Two factors apparently contributed to the greater amount of growth which occurred in lysimeter III. First, there was more water present in the soil than in number IV. Second, smaller quantities of soluble nutrients had been removed in the drainage water prior to sowing of the seed. It is interesting to note that if the nitrogen present in the tops of the oat plants is added to the amount removed in the percolate as nitrates, from the respective lysimeters, the totals are 0.6642 gram removed from lysimeter III and 0.6680 gram removed from lysimeter IV. Although the degree of significance of such a comparison is in doubt, it suggests that a certain amount of readily available nitrogen was present and that which was not removed in the drainage water was obtained by the plants, after aeration of the soil was improved through removal of water by the plants.

Two general conclusions might be drawn from this work. First, the data indicate that when the amount of moisture in a lysimeter is adjusted to correspond more closely with that in a natural soil, significant changes occur in the volume and composition of percolate. Second, the method which was used for correcting this error in lysimeter work shows considerable promise of being valuable for that

purpose. Further tests must be made, however, before extensive use is made of the method. It may be that in larger lysimeters the single tensiometer cup of the type used here will not be adequate for removing the water uniformly; but there appears to be no reason for not using more cups or a single unit with a larger porous area exposed to the soil.

The tension used in this work for aiding drainage was selected arbitrarily as being great enough to reduce the soil moisture to the point where diffusion of air would be greatly improved. Any tension from 0 to 60 cm of mercury column could be employed. It would seem feasible to have the tension controlled automatically so that it would be at all times the same as that which exists in a nearby (or even distant) natural field soil.

The degree to which results from larger lysimeters exposed to natural climatic conditions will differ from those reported in this paper will, of course, have to be determined by experiment. One might expect, however, that low atmospheric humidity would accentuate the difference in rate of evaporation. The relative humidity in the greenhouse varied during the course of this experiment from 30 to 50%, and was therefore considerably higher than that which commonly occurs under field conditions. On the other hand, the soil temperatures in these greenhouse lysimeters were undoubtedly higher and more uniform than would occur in lysimeters which are set in the ground. This factor might have affected moisture movements to some extent and also may tend to accentuate the differences in microbiological activity.

SUMMARY

Four small lysimeters were assembled in a greenhouse. Two were allowed to drain by gravity, according to the usual procedure. In the other two drainage was aided by the application, through tensiometer cups, of a tension equivalent to about 10 cm of mercury column.

As a result of this improved drainage, the rate of evaporation of water from the lysimeter was decreased, volume of percolate increased, content of nitrates and calcium in percolate increased, and growth of plants decreased.

Since this procedure rendered moisture conditions more nearly like those occurring in naturally well-drained soils, it was concluded that the abnormal moisture conditions in the ordinary type of lysimeter cause important errors in lysimeter studies. The method used here for correcting these conditions appears to offer possibilities for general use in lysimeter installations.

NOTE

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A NEW METHOD FOR ALFALFA EMASCULATION[1]

THE suction method of emasculating alfalfa and sweetclover has been recognized as a more or less standard procedure. Results obtained at the Nebraska Experiment Station, however, have indicated that there is some doubt as to the thoroughness of such emasculation procedure. Tests comparing different methods were made in the greenhouse during the winter of 1939–40. When suction was used and no foreign pollen applied to the stigma, 14.11% of the flowers formed pods. If suction plus washing with a stream of water was used and no foreign pollen applied, 5.50% of the flowers formed pods.

The suction for use in this test was obtained from an electrically driven small suction pump which gives somewhat more suction than the intake manifold on a car, and great care was followed in making the emasculations.

In contrast with this method of emasculation, a new method using alcohol gives very few pods when the checks are allowed to develop without applying foreign pollen. The new method is performed essentially as follows: The standards are first clipped from the flowers in full bloom with sharp scissors and then the flowers are tripped, thus leaving the stigmatic column exposed for treatment. All the flowers to be emasculated on the raceme are treated in this manner. If the raceme has numerous flowers, it will usually be found more convenient to remove some of them to facilitate working. The whole raceme is then immersed in a small beaker containing 57% ethyl alcohol for 10 seconds. The raceme is then immediately transferred to a beaker containing water where it is rinsed for a few seconds, after which it is ready for pollination with the desired pollen. It apparently makes little difference if the pollen is applied immediately after emasculation or as much as an hour after emasculation, provided the adhering water is blown off the stigma before the pollen is applied. It is also well to blow the adhering anthers back from the stigmatic surface to allow contact for the foreign pollen. A convenient instrument to provide a stream of air is a dentist's syringe, or a bulb from an atomizer.

A number of tests have been conducted in the greenhouse, using different strengths of the alcohol and different time intervals. The results of these tests are given in Table 1, together with comparable tests of emasculation by suction, with and without the use of water.

These tests were run on comparable racemes of the same group of plants and thus the results between treatments can be directly compared. Too high a concentration of alcohol or too long a treatment injures the flower, resulting in fewer pods set. For example, 66.5% alcohol for 30 seconds practically kills the flower. A total of 14.7% of

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station, Lincoln, Nebr., as Journal Series Paper No. 261.

the flowers formed pods when foreign pollen was applied after treating with 66.5% alcohol for 10 seconds, indicating some injury to the flower. This concentration gave good control, however, as only 0.78% of the flowers formed pods after emasculation. Controlled emasculation is not obtained by 66.5% alcohol for 1 or 5 seconds. On the other hand, 47.5% alcohol, at least for short periods of treatment, does not appear to be sufficiently strong to effect complete emasculation, since 3.10% of the flowers formed pods. For practical purposes 57% alcohol to be sufficiently strong and yet does not greatly injure the capacity to set seed, since 26.3% of the flowers set pods after pollinating with foreign pollen. This, however, is still somewhat lower than the untreated or suction-treated flowers which set 76.4% and 60% pods, respectively. The recommended time for the treatment with alcohol is 10 seconds, although some slight degree of latitude may be permissible with 57% alcohol.

TABLE 1.—*Percentages of alfalfa flowers forming pods after emasculation with different concentrations of alcohol compared to suction emasculation and to non-emasculated flowers, with and without foreign pollen added in each case.*

Emasculation method	Time immersed in alcohol, seconds	Number of flowers treated	Percentage of flowers forming pods	
			No pollen added	Foreign pollen added
47.5% ethyl alcohol*	10	198	3.10	41.4
57.0% ethyl alcohol	10	219	0.89	26.3
57.0% ethyl alcohol	10	50	——	32.0†
66.5% ethyl alcohol	1	98	5.10	——
66.5% ethyl alcohol	5	130	3.10	32.3
66.5% ethyl alcohol	10	256	0.78	14.7
Suction	—	156	14.11	60.0
Suction + washing	—	110	5.50	32.7
None	—	348	36.10	76.4

*47.5%, 57%, and 66.5% alcohol can be conveniently obtained by using 50%, 60%, and 70% of 95% alcohol, respectively.

†One hour allowed to elapse between the time of emasculation and pollination; this is not, however, significantly higher than a comparable treatment pollinated immediately after emasculation. With this one exception all pollinations were made immediately after emasculation.

Pollen was collected from anthers after the anthers were treated with 57% alcohol for 10 seconds and tested for germination along with untreated pollen. Out of 33 tests only one of the treated sets showed any germination. In this one set, 2% of the pollen grains germinated and these had a very poor growth. On the other hand, the untreated pollen germinated from 10% to 80%, averaging 33%. Similar pollen, within the anthers, immersed in water for 15 seconds germinated an average of 15%.

Other experiments conducted at this station have shown that, if foreign pollen is applied to the stigma in addition to its own, it is the effective agent in fertilization from 70% to 98% of the time (unpublished data). Thus, if crosses are to be made which can be distinguished from selfs in the F_1, or, if it is not important that 100%

crossing is obtained, such crosses might be made without previous emasculation.

On the other hand, where care must be taken to produce known hybrids, it would seem that the emasculation by suction technic is not sufficiently accurate. The alcohol technic gives much better control. The use of alcohol for emasculation in alfalfa appears to be practical on either a small or a large scale and is much faster, simpler, and more efficient than the suction method.—H. M. TYSDAL and J. RUSSELL GARL, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.*

BOOK REVIEWS

GROWING PLANTS IN NUTRIENT SOLUTIONS

By Wayne I. Turner and Victor M. Henry. xiii+154 pages, illus. New York: John Wiley & Sons, Inc. 1939. $3.

THIS book covers in a thoroughly practical manner the important considerations in growing plants in nutrient solutions, with special reference to commercial greenhouse culture. It comes from the hands of practical men who have been successful greenhouse operators and therefore emphasizes certain practical features, which are not present in all books available on this subject. It tells how to build the benches, how to convert old arrangements to the new method, how to plan the greenhouse, how to compute formulas, how to diagnose difficulties, what equipment to get and where to secure it. It is well illustrated with photographs from successful commercial set-ups and with outline drawings indicating types of equipment and methods of procedure. As a practical handbook it is one of the best along the newer lines of growing plants in nutrient solutions. (H. B. T.)

THE METEOROLOGICAL GLOSSARY

Issued by the Meteorological Office of the British Air Ministry. New York: Chem. Pub. Co. Ed. 3 (first American edition). 251 pages, illus. 1940. $3.

THIS book is a condensed manual of meteorology arranged alphabetically. While all the terms and concepts are explained tersely, there is much additional matter including tables, equations, constants, etc., which are of use to meteorologists and other scientists studying weather phenomena. In numerous instances three or four pages are devoted to information under a single term.

The work is very complete, including terms and concepts of physics, thermodynamics, statistics, chemistry, and geology which are used in the study of meteorology. The illustrations consist of graphs, weather maps, and classification of cloud formations. A section is devoted to the equivalent of English terms in Danish, Dutch, French, German, Italian, Norwegian, Portuguese, Spanish, and Swedish.

The text is well written, the presswork and binding well done, and the book should be welcomed by all who have occasion to refer to weather conditions and especially by agricultural scientists who study weather in relation to crops and pests. (F. Z. H.)

AGRONOMIC AFFAIRS

REPORT ON BIOLOGICAL ABSTRACTS TO THE UNION OF AMERICAN BIOLOGICAL SOCIETIES

THE steady conservative development of BIOLOGICAL ABSTRACTS continues. The Board of Trustees and editorial management are committed to a policy of prompt publication of authoritative and scholarly abstract issues and indexes, and every possible effort is being made to achieve both completeness of coverage and promptness in reporting the current literature of biology.

During 1939, 18,108 research papers were abstracted in BIOLOGICAL ABSTRACTS, an increase of 11% over the number of abstracts published the previous year. Coverage is still incomplete, but is being extended rapidly. By the end of 1939 arrangements were in effect for the regular, prompt abstracting of 1,150 of the world's most important biological periodicals, comprising, with scarcely an exception, the important English, French, and German serials in each department of biology.

Further expansion of coverage is necessarily dependent upon increased income. We can publish no more than we can pay for. Both as a safeguard against curtailment of foreign subscriptions and to finance desired improvements, increased subscriptions are necessary.

Every possible effort is being made to improve the quality of the service of BIOLOGICAL ABSTRACTS in every branch. Consultations with members of the Board of Trustees, members of the committees appointed by the various national societies, the Section Editors, and interested biologists generally, are almost constantly in progress and suggestions for improved coverage of the research literature are steadily being put into operation. In this connection we acknowledge with deep appreciation the services of Dr. E. V. Cowdry, retiring President, Dr. A. J. Carlson, the newly-elected President, and Dr. George W. Hunter, III, Secretary, of the Union, in providing effective contact between the BIOLOGICAL ABSTRACTS' organization and the national biological societies.—JOHN E. FLYNN, *Editor-in-Chief*, BIOLOGICAL ABSTRACTS.

SPECIAL SUMMER COURSES AT TEXAS A. & M. COLLEGE OF INTEREST TO AGRONOMISTS

THE DEPARTMENT OF AGRONOMY of the Agricultural and Mechanical College of Texas announces four special short courses this summer which will be of interest to agronomists. Each course will carry three hours credit and will be open to advanced undergraduate and graduate students.

FOREST SOILS—June 10 to July 20—taught by Dr. Robert F. Chandler, Jr., Pack Assistant Professor of Forest Soils, Cornell University. This is an advanced study of soils as they relate to forested areas. The course will also consider the climatic, physiographic, and biotic relationships of the typical southern pine forests, and the tension zone where the humid forest areas meet the semi-arid tall grass prairie of the Southwest.

RANGE MANAGEMENT AND ECOLOGY—June 10 to June 29—by Dr. W. G. McGinnies, Chief of Range Research Southwestern Forest and Range Experiment Station, Tuscon, Arizona. This course deals with range problems in the area west of the one hundredth meridian. The productive and carrying capacity of range land types of native vegetation, the possibilities of re-vegetation, principles of management and restoration, and a review of research work in the field will be studied.

PASTURES AND FUNDAMENTALS OF GRASS AND PASTURE IMPROVEMENT—July 22 to August 10—by Dr. F. D. Keim, Chairman, Department of Agronomy, University of Nebraska. The pasture problems of the Great Plains and the eastern half of the United States will be studied together with a review of pasture work throughout the world. The botany, the genetics, and improvement of pasture plants, and the principles of pasture research, ecology, and management will be studied exhaustively.

SOIL CLASSIFICATION AND MAPPING—August 12 to August 31—by Mr. E. A. Norton, Chief, Physical Surveys Division, Soil Conservation Service, Washington, D C. In addition to a review of soil genesis, classification, and associations, emphasis will be placed on classes of land according to use capability, together with all types of surveys and field studies useful in the determination of a soil's character and use capability The relations of large scale operations in this field will be considered from the standpoint of general agronomic import.

The above courses are designed primarily for professional workers. Those interested should write to Dr. Ide P. Trotter, Head, Department of Agronomy, Agricultural and Mechanical College of Texas, College Station, Texas, for further literature or information.

DOCTOR A. J. PIETERS AND PROFESSOR O. W. DYNES

THE AMERICAN SOCIETY OF AGRONOMY has lost two notable members of its group by death in the persons of Doctor A. J. Pieters of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and Professor O. W. Dynes, Head of the Department of Agronomy, University of Tennessee.

Doctor Pieters died April 25 in his 74th year, and at the time of his death was in charge of the Lespedeza investigations being carried on by the Department. He had been associated with the U. S. Dept. of Agriculture since 1895 and had long been an active member of the American Society of Agronomy.

Professor Dynes died on May 6 at the age of 59. Professor Dynes became Head of the Department of Agronomy at the University of Tennessee in 1928 and Associate in Agronomy at the Experiment Station in 1936. He was a specialist in corn breeding and was an active member of the American Society of Agronomy and the Soil Science Society of America.

NEWS ITEMS

THE SOIL SCIENCE SOCIETY of Florida held a symposium on the afternoon of April 2, immediately preceding the meetings of the State

Horticultural Society at Tampa, in which the possibility of using soil reaction values expressed as pH as a basis for a liming program was discussed in detail. The state-wide interest in the problem was indicated by an attendance of over two hundred members and visitors.

GAYLORD M. VOLK, formerly Associate Soil Scientist in charge of the Soil Conservation Service Laboratory of Region 8, Albuquerque, New Mexico, has assumed the duties of Soil Chemist in charge of Soil Fertility Investigations at the Florida Experiment Station, Gainesville, Fla.

OWEN E. GALL, Research Assistant in Soil Chemistry at the Florida Agricultural Experiment Station, was recently appointed Junior Soil Scientist in the Soil Conservation Service.

THE IMPERIAL BUREAU OF PLANT BREEDING AND GENETICS, School of Agriculture, Cambridge, England, has published a bibliography on cold resistance in plants (price 1/6) and a pamphlet entitled "Field Trials: Their Lay-out and Statistical Analysis" by John Wishart (price 2/6).

DR. R. B. MUSGRAVE, who completed the requirements for the Ph.D. degree at the University of Illinois this year, has been appointed Assistant Professor of Agronomy at Cornell University. Dr. Musgrave will give special attention to problems in field crop ecology.

PRESIDENT F. J. ALWAY designated the following persons to act as delegates from the American Society of Agronomy to the Eighth American Scientific Congress in Washington, D. C., May 10 to 18: Dr. Oswald Schreiner and Dr. Richard Bradfield on the Section of Physical and Chemical Sciences and Dr. G. G. Pohlman, Dr. M. A. McCall, and Dr. C. E. Kellogg on the Section of Agriculture and Conservation.

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CALCIUM-POTASSIUM-PHOSPHORUS RELATION AS A POSSIBLE FACTOR IN ECOLOGICAL ARRAY OF PLANTS[1]

WM. A. ALBRECHT[2]

PLANT distribution and growth depend mainly on climatic factors. The soil in which plants grow is a resultant also of climatic forces. Consequently, we may well raise the question whether the degree of soil development or extent of nutrient depletion resulting from varying intensities of the climatic forces may not serve as an index to the ecological array of plant species. With the soil development and the plant distribution both determined by the same climate, then the nature of the soil and the distribution of the plants should agree. Which of the characteristics of the soil might control such an agreement, is a question that may well challenge speculative consideration.

Nitrogen, calcium, phosphorus, and potassium represent, in general, the major portion of soil fertility, or plant nutrient supply. Since the ultimate source of nitrogen is the atmosphere, then the plant nutrients of soil origin which are more commonly limiting plant growth, at least of legumes, can be considered to consist of calcium, potassium, and phosphorus. Further, since the variations in these three elements also dominate in the degree of soil development, may we not then look to the possibility that these same variations which reflect the effects of climate on the soil might also determine the ecological array? Some evidence and suggestions in support of such a possibility will be given consideration.

COMPOSITION OF VEGETATION REFLECTS INFLUENCE OF THE NUTRIENT DOMINANT IN THE SOIL

It is commonly agreed that potassium functions within the plant in carbohydrate production. In general, more potassium is required as more carbohydrate is produced. Potato tubers of almost pure starch, or carbohydrate composition, contain significant amounts of potassium. Sugar beets, sugar cane, sorghums, and other saccharine

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo., Journal Series No. 635. Also presented before the Crops Section at the annual meeting of the Society in New Orleans, La., November 22, 1939. Received for publication February 16, 1940.

[2]Professor of Soils.

crops make a decided demand on the soil for potassium. Perhaps we should discriminate whether this demand is for excessive amounts per acre annually along with similarly large amounts for other nutrients, or whether potassium is required in possibly no excessive total amounts but mainly in large amounts in comparison to other nutrients. Potassium or lye leachings from the ash of wood are known from the ancient arts. Forest soils, in general, are considered as low in phosphorus and badly leached of calcium. Though not absolutely rich in potassium, they may be relatively so.

The functions of phosphorus are commonly associated with reproduction, cell multiplication, growth, or protoplasmic activities, all of which are centered about a proteinaceous composition. Protein is characterized roughly as though it were a carbohydrate into which phosphorus and nitrogen have been combined. Phosphorus and nitrogen are thus associated with proteins while potassium dominates in carbohydrates.

Since calcium is a component of neither of the two preceding different composition groups that serve as constituents for the major portion of all plants, it might seem but fanciful imagination to give it importance as an ecological factor operating through protein production. Recent studies (4)[3] have given it an important role in nitrogen fixation by legumes. We may also well raise the question whether we understand fully its role in nitrogen metabolism of non legumes when we see their increased protein content by calcium treatment explained so casually as originating in the increased nitrogen supply from improved soil nitrification by liming as a soil treatment.

Studies (9) of the composition of grasses with increased protein brought about by liming suggest for calcium a much less indirect role in bringing about this improved activity in the production of protein. Thus, calcium may be significant in the formation of this type of nitrogenous compounds because it is connected with the process of bringing into the protein its characteristic nitrogen and possibly phosphorus. Calcium may thus be a controlling factor in ecology, and its wide fluctuation either as total supply in a soil or as saturating part of the adsorption complex may give it a larger role than is readily appreciated. Thus, if calcium functions strongly in nitrogen fixation and the consequent protein production, if phosphorus is likewise instrumental in augmenting this process, and if potassium is associated in the main with carbohydrate production, might we not expect that such soil conditions as allow one or the other of these elements to dominate in the nutrient supply will give dominance to one or the other of these corresponding functions in the flora?

CALCIUM-POTASSIUM-PHOSPHORUS AS VARIABLES WITH THE PHOSPHORUS LOW OR ALMOST A CONSTANT

Three variables present difficulties of determination by means of limited numbers of equations in experimental problems. Hence, since phosphorus is usually so low in most soils as to be considered almost the common regularly limiting factor, we may roughly reduce the

[3]Figures in parenthesis refer to "Literature Cited", p. 418.

variables in this case to calcium and potassium. If we may consider that phosphorus is a constant in nature when it is so low in quantity, so low in chemical mobility, and roughly at such a low base level above which the other two vary so much more widely, then the equations will include but two variables, calcium and potassium, for the problem in question here. If phosphorus is constant, then the calcium-potassium relations become the controlling factors in the ecological array and will not be so difficult of study. These two, under such an assumption, will be given the main attention in this discussion.

WHEN ARRANGED IN ORDER OF DECREASING PROTEIN CONTENT, PLANTS HAVE DECREASING NUTRIENT MINERAL CONTENTS

Studies (7) of the nitrogen contents, particularly of crops and vegetable plants, have made possible an array with different plants following in the order of decreasing protein or nitrogen contents. The legumes stand at the head of the list. Beginning with alfalfa, for example, followed by red clover, sweet clover, and others, including garden legumes, these crops can be arranged according to decreasing protein contents and lowering feeding or nutritional values commonly accepted in farm and household practice. As one goes down the scale to some of the legumes grown in the southern states, and of less nutrient value, there is still lower protein content, or lower total protein production per acre, and correspondingly lower total mineral content, particularly of calcium. Thus, there is less mineral per acre taken from the soil. The crops yield less protein per acre as their mineral supply decreases. With minerals coming only from the soil, its contribution of these may thus control the protein yield by the crop.

In arranging this order of decreasing protein production per acre by the legumes, there is no great gap in going from the lower legumes to those nonlegumes of higher feeding value. This higher value is also connected with the greater nitrogen content or total nitrogen in the crop. Hays from wheat, barley, rye, oats, bluegrass, timothy, redtop, and meadow fescue arrange themselves in this order of decreasing protein composition and reflect their commonly accepted hay values in the same order.

This arrangement with reference to higher proteinaceous nature of the different species, both legume and nonlegume, might serve as a pattern against which there can be matched also the calcium-potassium requirements as concentrations within the crop or the needs per acre. Studies (7) show the calcium decrease to go parallel with the nitrogen decrease, particularly in concentration within the plant. They reflect also different yields of total protein and nutrient minerals per acre in this general arrangement. When the potassium in the more commonly accepted field and vegetable crops is charted in this array according to decreasing calcium taken, or nitrogen delivered, by the crop, there is not the close agreement shown between calcium and nitrogen. Perhaps no great variation in the carbohydrate, or carbonaceous, part of the plant that amounts to a total of 50% need be expected even when there is a decided variation in protein of

which the total content scarcely ever exceeds 5%. Sampling for nitrogen variation over so narrow a range may not represent random sampling for the potassium associated with the carbohydrate. With these feed crops already selected according to animal choice for feed significance, the range in potassium may still not be wide enough to represent its possibilities for variation. When one considers woody plants, or takes woody tissue as an illustration, the dominance of potassium as compared to nitrogen and phosphorus is characteristic. Thus, we may regard potassium consumption as characteristic for the wood producers or for plant skeleton production, and calcium and phosphorus consumption as characteristic for the producers of protein. Perhaps it might be simpler to consider that all plants use some amounts of all nutrients but that with a low phosphorus level in all soils, the protein-producing plants are more common when calcium dominates in the soil supply, while with the decline or exhaustion of calcium the potassium dominates not necessarily by magnitude but by contrast. It is then that the more carbonaceous, or less proteinaceous, vegetation prevails.

SOIL DEVELOPMENT SUGGESTS DECREASING EXCHANGEABLE CALCIUM IN RELATION TO EXCHANGEABLE POTASSIUM

If this reasoning is sound, then the plant ecological array bids fair to be fitted into the complex picture of soil development according to climate. By accepting the colloidal clay particle as the nutrient-supplying nucleus of the soil, let us first consider it as neutral in reaction, and stocked liberally with the exchangeable cations of nutrient significance. Such a soil nucleus is characteristic of the chernozem soils produced in climatic areas where precipitation and evaporation are almost in equilibrium and temperatures are moderate. With increasing rainfall at such temperatures this nucleus exchanges the nutrient cations for the hydrogen ions of non-nutrient value. Consequently, the nucleus becomes acid. As the temperature becomes higher under liberal or excessive rainfall, this nucleus is broken down into less complex structures or compositions with less adsorptive or exchange capacity for nutrient cations. It likewise is less capable of holding exchangeable hydrogen ions or of showing significant degree of acidity. Thus, in the temperature zones, the complex nucleus of variable exchangeable calcium content is the characteristic of the soil. It usually has decreasing calcium with increasing hydrogen (and aluminium) as roughly the reciprocal under increasing degrees of leaching. In the warmer regions the simpler clay complex or nucleus carries little calcium and holds less of all nutrient contents.

ARTIFICIALLY DEVELOPED SOIL SHOWS NARROWING RATIO FOR EXCHANGEABLE CALCIUM-POTASSIUM

As an aid in visualizing the changes within the soil colloidal complex while a soil develops or passes to higher degrees of weathering and greater nutrient loss, some research in Holland by Prillwitz (8) may be helpful. The soil was weathered artificially through sulfur treatment and its microbiological oxidation. The change in the clay

complex is shown in Fig. 1, representing the exchangeable cation variation and the loss in some of its exchange capacity. According to this scheme, one of the distinct features is the substitution for the bases by the hydrogen and aluminium. Still more distinct is the fact that the relative amount of calcium is depleted much more rapidly than any other exchangeable nutrient on the complex. With the in-

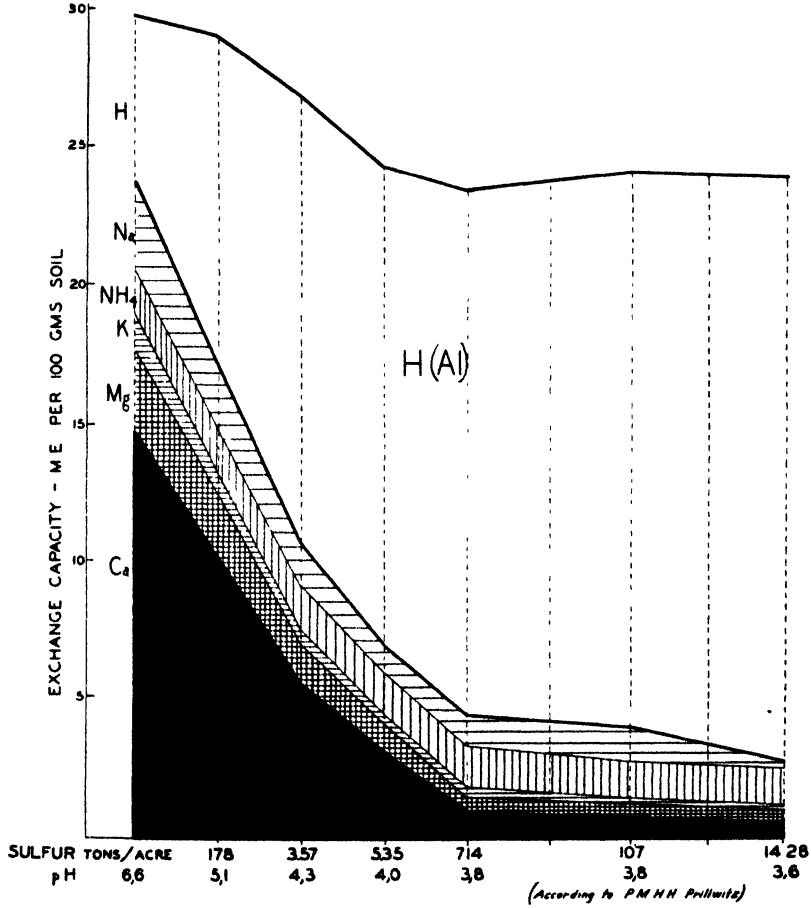

FIG. 1.—Varying relations of exchangeable cations, particularly Ca:K in a clay loam weathered to different degrees by sulfur additions.

creasing degree of soil development, the ratios of bases to each other shift, but of all the items, the calcium undergoes the greatest change. The ratio of this element to potassium shifts from approximately 11.0:1.0 at the pH figure of 6.6 to 4.0:1.0 at the pH figure of 3.8. If the anion of phosphorus is low at the outset and remains constantly so, then this shift in ratio of the calcium to potassium represents a decided change in the ratios of the nutrient offerings by a soil, even if the increasing clay content as a disturbing factor in offering of

totals is disregarded. The question may then well be raised whether such shifts in exchangeable cations may not be basic for an ecological shift from proteinaceous to non-proteinaceous plant dominance, or at least to less proteinaceous vegetation, as the soils are more highly developed and the clay complex simplified to a higher degree by the increasing forces of climate in the form of more rainfall or increasing temperature.

EXPERIMENTAL SHIFTS IN THE CALCIUM-POTASSIUM RATIO BRING SHIFT IN LEGUME FROM PROTEINACEOUS TO CARBONACEOUS PRODUCTION

As experimental help pointing toward the possible validity of the suggested array of dominant proteinaceous vegetation with high calcium to potassium ratio, let us note the behavior of soybeans as the calcium-potassium ratio was varied under control. When grown on a constant (5) but low phosphorus level, a constant but liberal calcium level, and with increasing potassium, all in the exchangeable or readily available form for the plant, this legume demonstrated a suggested shift from a proteinaceous producer to a carbonaceous producer. This is shown in Table 1. When the calcium relative to

TABLE 1.—*Decrease in nitrogen fixation and increase in crop weight of soybeans with widened calcium-potassium ratio.**

Exchangeable cations, M.E.			Crop weight, grams	Nitrogen		Magnesium		Calcium		Phosphorus		Potassium		K%/Ca%
Mg	Ca	K		%	Mgm	%	Mgm	%	Mgm	%	Mgm	%	Mgm	
5	10	0	14.207	2.86	407	0.36	52	0.74	105	0.25	39	1.01	150	1.36
5	10	5	14.592	2.56	372	0.36	54	0.32	46	0.18	26	1.90	285	5.93
5	10	10	17.807	2.19	390	0.30	55	0.27	48	0.14	25	2.15	384	7.96

*Seed content in mgm: N = 364, Mg = 16.7, Ca = 12.2, P = 39.4, K = 171.

potassium supply was high, this plant was a nitrogen fixer of moderate growth. When the increase in potassium was introduced so that the calcium was relatively low in relation to it, this plant grew larger, but its nitrogen-fixing activity dwindled. It consumed the offered nitrogen but diluted this with carbohydrate production. If it is true that this shift from protein to carbohydrate follows the shift in calcium-potassium ratio in the soil in the case of a single plant species, may it not be an epitome of the evolution of the ecological array of plants in accordance with the degree of development of our soils as measured by this shift in calcium-potassium ratio?

OBSERVATIONS ON SOIL DEVELOPMENT AND GENERAL VEGETATION AS POSSIBLE SUPPORT OF THE THEORY

It is commonly granted that dark soils are liberally stocked with calcium. It has been held by many that the calcium is the means of

preserving the organic matter. A different significance of the calcium seems more plausible in the light of studies of nitrogen fixation (1, 2, 6). Black soils naturally rich in calcium are usually correspondingly rich in all nutrient cations and are fit media for the mineral-consuming legumes. Calcium is significant for bringing nitrogen from the air to the soil. This added nitrogen serves to hold additional carbon as organic matter of nearly constant carbon-nitrogen ratio for each climatic location. Thus, soils high in exchangeable calcium produce more and retain more organic matter even though they also have their microbiological decomposition processes favored by these liberal stocks of cations (3). In going from these dark soils, according to the soil classification map, or to the rainfall map, to soils of lighter color with more rainfall at constant temperature, we go from prairies to forests and follow the general array of decreasing protein production and increasing carbonaceous, or wood, content in the vegetation. Increase in leaching means a soil complex whose potassium is still offered in exchangeable form in amounts to produce carbonaceous growth, and whose calcium and phosphorus levels maintain reproduction and cell multiplication sufficient to maintain this carbohydrate manufacture, but are not high enough to bring into this plant complex the extra nitrogen and phosphorus for plant types classified as distinctly proteinaceous.

In the extreme case of the forest tree we may visualize low calcium and phosphorus supply just sufficient to maintain a reasonable leaf area in metabolic activities of carbon assimilation and annual wood production. This leaf area may remain roughly constant with slight annual increase as it maintains itself at the top of the tree, with apical growth at the expense of translocation from the disappearing branches below. The pine in the sandy soils deficient in calcium but offering little potassium may illustrate the case with tall barren trunks tipped at great height by the green, photosynthetically active top. Students of the taxonomy of prairie vegetation have also reported the apparent increase in legume species in the prairie in going from east to west in Kansas or Nebraska, for example, or in going toward less leached soils or calcium carbonate horizons of less depth in the soil profile.

Since increasing temperature encourages soil development to the extent of colloidal clay breakdown, we must expect the well-developed or more highly simplified lateritic soil complex of lower exchange capacity to offer low amounts of calcium and to fit into the scheme as suggested. If such is true, the dominance of saccharine natured crops in the South would seem logical. The southern legume crops, when carefully studied, suggest that their properties fit them into soils of lower fertility when we know that they are more promiscuous in cross inoculation and in cross pollination, both of which are properties that aid in their struggle for maintenance against low soil fertility. Soils under high temperature and moisture have always been problem soils in fertility management. An application of the low calcium-potassium ratio theory and all that goes with it in the plant array may help us to understand some of the problems of agriculture in the South.

CALCIUM-POTASSIUM RATIO THEORY NEEDS FURTHER TESTING

Attention is not invited to the theory that the calcium-potassium ratio in soils of low phosphorus content controls, in a large measure, the ecological plant array because this theory has become a proved fact, but rather because, like many theories, whether ever proved or not, it may be helpful in making order out of chaotic thinking or of seemingly unrelated facts. If such an array is correct, can we not group our list of field crops for better adaptation to soils according to soil regions or to degree of soil development? Cannot soil treatment be used to improve the composition of the crops in the lower soil fertility phase of the natural ecological array? A fuller understanding of the relation of crops to soil conditions may reduce our search for crop plants from one of ramblings over the globe for promiscuous collectings and scatterings, to one of more carefully guided transfers from and to regions of common soil characters or even transfers to improved conditions for the crop.

It is for its possible help in clearer understanding of plants in relation to soil development and fertility that the calcium-potassium ratio theory suggested herewith is offered for your speculative consideration and for criticism.

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THE EFFECT OF LIMING ON THE ABSORPTION OF PHOSPHORUS AND NITROGEN BY WINTER LEGUMES[1]

Franklin L. Davis and Claud A. Brewer, Jr.[2]

ALTHOUGH the increased yield of crops is usually accepted as a measure of the effects of applications of lime and fertilizers to soils, there is evidence that the yield alone does not fully evaluate the effects of such treatments. Numerous investigators (5)[3] have shown that the composition of plants varies with the composition of the soil on which they grow and that infertile soils produce crops low in mineral and protein content. Others (9) have shown that applications of fertilizers to poor soils usually result in an increased content in the plant of the elements supplied by the fertilizers. Such increases in the mineral content of feed and forage crops represent increased feeding value not measured by the yield.

Since calcium is the most abundant nutrient base found in normal soils, it is usually considered as being present in sufficient quantities for the normal nutrition of most crop plants, and liming the soil is looked upon as a practice to be used only when the soil becomes too acid to grow some desired crop. Chemical analyses of plants grown under field conditions prove that this is not always the case and show that crop yields may not be an accurate indication of the lime deficiency of soils. For example, Sewell and Latshaw (8) found that fertilizing with superphosphate did not increase the percentage of phosphorus in alfalfa, but that applying lime with the superphosphate did. Albrecht and Klemme (1) have reported field work in which applications of limestone and superphosphate almost doubled the calcium, phosphorus, and protein content of lespedeza forage over that obtained from superphosphate alone. These data show that the absorption of phosphorus and nitrogen was increased by liming and indicate that soils may be deficient in calcium without crop yields being seriously affected.

In a study of the factors affecting the inoculation and growth of winter legumes in Louisiana, data have been obtained on this subject. They show that liming increased the absorption of calcium, phosphorus, and nitrogen by winter legumes and that many Coastal Plains soils may be so deficient in calcium as to curtail seriously the normal absorption of phosphorus by crop plants even when it is supplied by fertilizer applications.

EXPERIMENTAL

Both Austrian winter peas (*Pisum arvense*) and common vetch (*Vicia sativa*) were planted in cooperation with farmers at various locations throughout the

[1]Contribution from the Department of Agronomy, Louisiana Agricultural Experiment Station, University, La. Paper presented at the Forty-first Annual Convention of the Association of Southern Agricultural Workers held in Birmingham, Ala., February 7, 8, and 9, 1940. The work reported was supported in part by a grant of funds made by The Urbana Laboratories, Urbana, Ill. Received for publication March 6, 1940.

[2]Associate Soil Technologist and Graduate Fellow, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 424.

state. Each test included plantings of both crops on separate plots as follows: Plot 1, uninoculated, not fertilized; plot 2, inoculated, not fertilized; and plots 3 to 8, inoculated and fertilized with various fertilizer and lime treatments. Superphosphate containing 18% P_2O_5 was applied at the rate of 225 pounds per acre at the time of planting and 1,000 pounds per acre of lime were applied, either at the time of planting or a week or 10 days before.

Essential information concerning the location of the tests, the character of the soils, and the dates of planting and cutting are given in Table 1. Yield weights were obtained by weighing replicated cuttings from each treatment at the time of turning under the crop. Weighed samples of the green matter were taken at the same time for chemical analyses.

TABLE 1.—*Location of test, soil type, exchange capacity, exchangeable calcium, and dates of liming, planting, and taking yield weights.*

Soil No.	Location (parish)	Soil type	Date of liming, 1937	Date of planting, 1937	Date yield weights taken	Base exchange capacity, M.E. per 100 grams	Exchangeable calcium, M.E. per 100 grams
212	Natchitoches	Ruston sandy loam	Sept. 21	Sept 30	Mar. 11	1.89	1.20
215	Ouachita	Orangeburg fine sandy loam	Sept 20	Oct. 1	Mar. 28	1.75	1.03
216	Washington	Cahaba fine sandy loam	Oct. 11	Oct. 11	Mar. 23	4.00	1.40
217	St. Landry	Lintonia t. loam	Oct. 13	Oct. 13	Feb. 28	7.45	2.15

The results of the field work in detail and recommendations concerning the culture of the legumes are given elsewhere (3). Only those data bearing upon the effect of liming on the growth and composition of the legumes are considered here.

RESULTS

Satisfactory inoculation and growth of the peas and vetch were obtained at four locations in 1937–38. The average growth and percentage composition of the green matter in calcium, phosphorus, and nitrogen of these crops are given in Table 2. The average total quantities absorbed per acre are also shown.

The data in Table 2 show that liming increased the total growth and absorption of calcium by the legumes whether they were fertilized or not. Where no superphosphate was applied, liming resulted in a decrease of the average percentage content of phosphorus with only a small gain in the total quantity absorbed per acre. Where superphosphate was applied, liming produced an increase in the average percentage content of phosphorus with a resultant large increase in the total amount absorbed per acre. The absorption of nitrogen behaved somewhat similar to that of phosphorus.

The data are presented graphically in Fig. 1. The graphs aid in visualizing the relative importance of increased growth and change in

TABLE 2.—*The effect of liming on the growth and composition of winter legumes.*

Treatment	Average moisture content of green matter, %*	Average yield, tons green matter per acre*	Average composition of green matter, %*			Average quantity absorbed per acre, lbs.*		
			CaO	P_2O_5	N	CaO	P_2O_5	N
Not Fertilized: Lime Alone Compared to no Treatment								
Lime	82.1	3.79	0.26	0.08	0.53	19.1	6.5	41.7
No treatment	81.8	2.95	0.20	0.09	0.51	12.4	6.2	31.5
Increase from lime	—	0.84	0.06	−0.01	0.02	6.7	0.3	10.2
Percentage increase from lime	—	28.3	27.3	−12.2	4.5	54.0	5.7	32.4
Fertilized with Superphosphate: Lime and Superphosphate Compared to Superphosphate Alone								
Lime and superphosphate	82.9	6.29	0.28	0.11	0.62	35.0	14.8	81.2
Superphosphate alone	82.8	5.25	0.23	0.10	0.55	25.0	11.0	60.5
Increase from lime	—	1.04	0 05	0 01	0.07	10.0	3.8	20.7
Percentage increase from lime	—	19.8	20.4	14.4	12.4	39.8	35.2	34.3

*Average of eight crops grown in 1937–38: four each of Austrian winter peas and common vetch.

composition in increasing the total amounts of calcium, phosphorus, and nitrogen absorbed. The increase in the absorption of calcium produced by liming is the result of both (a) an increase in growth and (b) an increase in percentage composition. In the case of phosphorus where no fertilizer was applied, there was only a small increase in the total amount absorbed. This small net increase is due entirely to an increase in growth since the average percentage composition was actually decreased. This can be ascribed to the effect of the lime on the solubility of native soil phosphorus. The increase in the amount of nitrogen assimilated where no fertilizer was applied is likewise almost wholly due to the increase in total growth. Quite a different picture is presented where superphosphate was applied. The increased absorption of phosphorus and nitrogen is due to both an increase in growth and an increase in the percentage content of the elements. Apparently liming enabled the plants to utilize larger quantities of the phosphorus supplied by the fertilizer application. And a corresponding increase in the assimilation of nitrogen also followed.

RELATION OF CALCIUM SUPPLY TO AVAILABILITY OF PHOSPHORUS

If a deficiency of calcium in soils limits the normal uptake of phosphorus by plants, as these data indicate, then the calcium supply of soils should throw some light on the relationship between the results of rapid tests for soil phosphorus and crop yields. With this in mind, data previously published by the senior author and others (4) on the

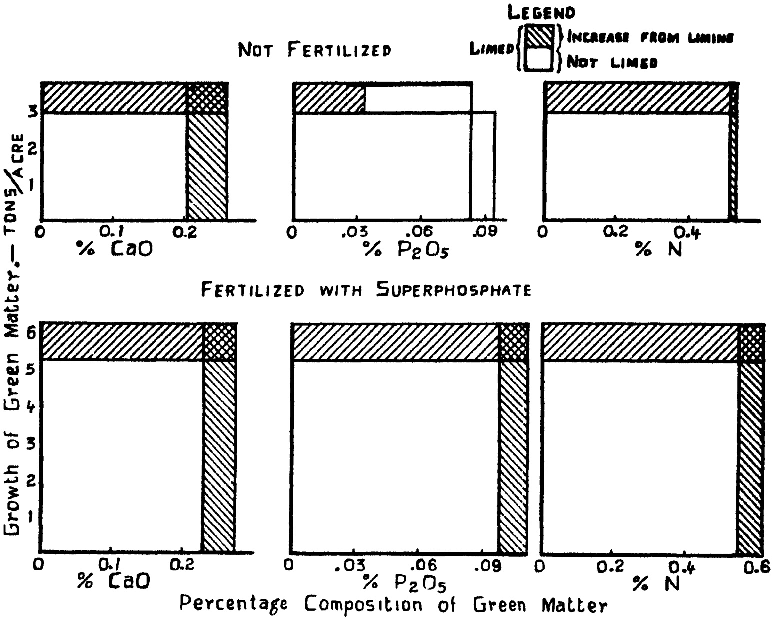

FIG. 1.—Effect of liming on the growth and composition of winter legumes.

correlation between crop yields and available phosphorus were reviewed. The graph showing the relationship between the amount of readily available phosphorus as determined by Truog's method and the yield of sorghum on 23 Greenville sandy loams is reproduced in Fig. 2. The values for the percentage calcium saturation of the soils were taken from Alabama Experiment Station Bulletin No. 244 (2) and are shown inserted on the graph.

It will be seen in Fig. 2 that all the soils on which the growth of sorghum (*Sorghum vulgare*) was considerably less than that expected from the quantities of available phosphorus present were low in exchangeable calcium. With but one exception, the degrees of calcium saturation were considerably less than the average (44.7%) for the entire group. In addition, those that produced more sorghum than was expected from the results of the available phosphorus test were considerably above the average in percentage calcium saturation. These data indicate that the calcium supply of soils is related to the utilization of soluble phosphorus by nonleguminous plants. This effect of calcium upon the absorption of phosphorus by plants warrants a careful examination in connection with the development of a rapid soil test for phosphorus suited to southern soils.

DISCUSSION

Liming soils fulfills two functions in connection with soil fertility and plant nutrition. First, it corrects soil acidity and produces a favor-

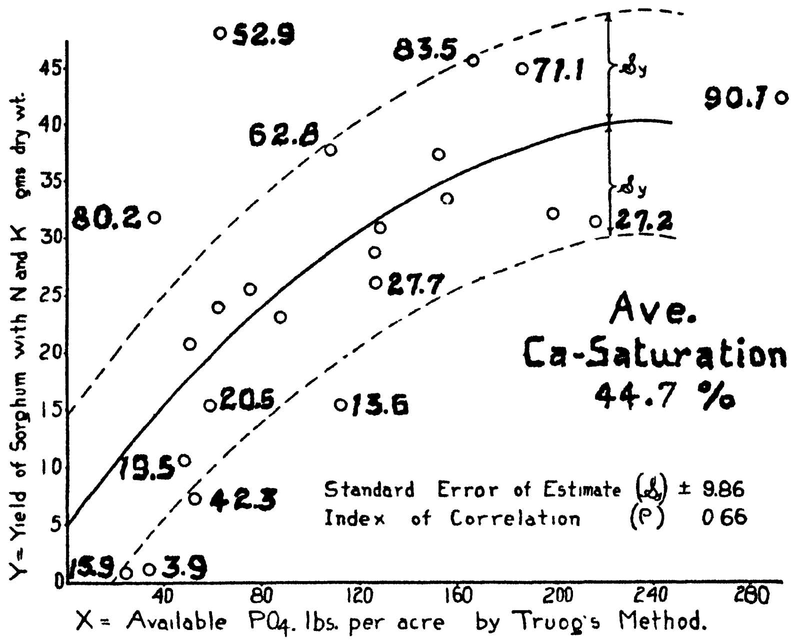

FIG. 2.—The percentage calcium saturation of soils as related to the relationship between the amount of readily available phosphorus and the yield of sorghum.

able reaction for the growth of plants. Second, it supplies calciu' a, or calcium and magnesium, needed for the nutrition of crops.

Soil reaction affects the solubility of most nutrient elements. At extremely acid reactions, toxic quantities of certain elements may be brought into solution. On the other hand, alkaline reactions often produce deficiencies by rendering essential elements insoluble. The maximum solubility of phosphorus, particularly, has been shown (7) to be dependent upon an optimum soil reaction.

The efficacy of liming in supplying nutrients has received much less attention than its effects upon soil reaction. It is known from work with nutrient solutions that a comparatively large quantity of calcium is essential to plant growth. Gedroiz (6) compared the growth of oats, and in some cases, of mustard and buckwheat, on a fertile soil to the growth obtained on quantities of the same soil with its exchange capacity saturated with each of the following bases: Hydrogen, ammonium, sodium, potassium, magnesium, calcium, strontium, cadmium, barium, manganese, ferrous iron, cobalt, nickel, copper, aluminum, and ferric iron. Only the calcium-saturated soil produced a crop growth equal to that of the original soil. Even when lime ($CaCO_3$) and nitrogen and phosphorus were added, a normal crop was obtained only from the hydrogen-saturated soil, on which the calcium replaced the hydrogen in the soil exchange complex. In 1921 True (10) found that the presence of a certain minimal quantity of

calcium ions was necessary for the normal absorption of ions of other elements. He also observed that the larger the variety of ions present the greater was the absorption of all electrolytes and the less marked the importance of the proportional concentration between ions.

The data obtained in this work are in line with these observations and serve to bring to our attention the stage of calcium depletion of many of our Coastal Plains soils. Because of the nature of the parent material the texture, and the warm, humid climate under which they have developed, Coastal Plains soils do not contain large quantities of nutrient elements even under virgin conditions. Their cultivation to cotton and tobacco for years has further depleted their supply of calcium. So long as these crops are grown, the need for building up the calcium supply does not become serious. However, with a reduction in the acreage of cotton and tobacco, these crops tend to be grown on the more fertile soils and the diverted acreage to consist mainly of the poorer lands. The use of these lands for pastures and the production of feed and forage is normal and should be encouraged. Such a utilization of soils low in calcium content will emphasize the problem of their fertility and make it increasingly important that their calcium supply be replenished by liming in order to produce larger yields of crops having a higher mineral and protein content.

SUMMARY

Both Austrian winter peas (*Pisum arvense*) and common vetch (*Vicia sativa*) were grown with various fertilizer treatments at a number of locations on upland soils in Louisiana. The composition of the soil and the growth and chemical analysis of the green matter produced were determined. The data show that liming soils low in calcium content enabled the crops to utilize larger quantities of the phosphorus supplied by applications of superphosphate. Lime alone produced an increase in percentage content of calcium only, while lime applied with superphosphate resulted in an increased content of calcium, phosphorus, and nitrogen.

Earlier data regarding the relationship between readily available soil phosphorus and crop yields are reviewed. These data further showed that those soils on which the yield of sorghum was unexplainably low in relation to the available phosphorus were also low in exchangeable calcium. It is thought that a low calcium content of soils will explain the lack of agreement between crop yields and rapid tests for phosphorus on many southern soils.

These facts are of the utmost importance to an expansion in the production of feed and forage crops on the upland soils of the southern states.

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GENETIC STUDIES WITH FOXTAIL MILLET, *SETARIA ITALICA* (L.) BEAUV.[1]

H. W. Li, J. C. Meng, and C. H. Li[2]

VERY little is known about the genetics of foxtail millet. Rangaswami Ayyangar[3], in 1934, summarized the work that he and his co-workers in India had done. In this summary, he mentioned the inheritance of purple pigmentation of plant, grain color, anther color, bristles, lax earhead, spikelet type bristle, and albino seedlings. Li[4], also in 1934, found that the waxy endosperm of millet is inherited in a simple Mendelian fashion.

While the first two authors were carrying out millet breeding work in Honan University, Kaifeng, Honan, in 1932, many varieties of millet were collected. Attempts were made in crossing various types to study their genetic behavior. Some natural hybrids were also observed and collected. The subsequent generations were grown in the breeding garden of the National Wuhan University, Wuchang, Hupeh. Unfortunately, the soil was rather sticky and the weather was too rainy for a good millet crop. Thus, the populations of the segregating generations were relatively small and the plants were considerably deformed Since 1938 the study has been continued at Chengtu, Szechuan, where the growing conditions for the millet are almost without an equal, even much better than those at Honan where the millet is grown most extensively. The results of these later studies are reported here.

SEED COAT COLOR

The mature grain of millet is enclosed by its lemma and palet which compose the seed coat. In the varieties of millet collected in Honan, there are five distinct color types for the seed coat, *viz.*, black, tawny buff, korra buff, red, and tawny red. While Rangaswami Ayyangar's description was closely followed, the classification was not always an easy one, the color varying tremendously with degrees of maturity. For instance, an unripe earhead with black seed coat is not black at all but tawny or korra buff in most of the seeds, although some seeds showed some black color. Again, there are many shades for the five color types mentioned, especially for the tawny buff and the red types. Nevertheless, when one is acquainted with the material, little difficulty will be encountered except with immature seed. It is fully realized that some of the data on color inheritance are rather meager, but they are presented here for what they may be worth.

[1]Contribution from the Department of Farm Crops, Szechuan Provincial Agricultural Improvement Institute, Chengtu, Szechuan, China. Received for publication March 6, 1940.

[2]Head of the Department and Associate Agronomist, respectively.

[3]Rangaswami Ayyangar, G. N. Recent work on the genetics of millets in India. Madras Agr. Jour., 22:1–11. 1934.

[4]Li. H. W. Studies in the breeding methods for the foxtail millet. (In Chinese.) Col. Agr., Honan Univ. Bul. 2:1–21, 1934.

RED × KORRA BUFF

F_1 of the cross red × korra buff is tawny buff in color. The population in the F_2 is composed of four types, *viz.*, tawny buff, korra buff, red, and tawny red in a 9:3:3:1 ratio, as shown in Table 1.

TABLE 1.—*F_2 progenies of red × korra buff.*

P_1		F_1		F_2			
Color	Pedigree	Color	Pedigree	Tawny buff	Korra buff	Red	Tawny red
Red × korra buff	1-1	Tawny buff	111	20	7	8	1
Red × korra buff	1-2	Tawny buff	112	23	8	7	1
Red × korra buff	1-3	Tawny buff	113	16	9	8	1
Red × korra buff	1-5	Tawny buff	115	17	4	7	2
		Observed		76	28	30	5
		Calculated 9:3:3:1		78.12	26.04	26.04	8.68

P = .5

The probability of such a deviation from the expected value is 1 5. Similar deviation might therefore be expected once in two trials. Thus, the ratio of 9:3:3:1 denotes the action of two factors. Red might be assigned to a factor k and korra buff to r. Hence the four phenotypes will have the following factorial assignment:

Tawny buff KR
Korra buff Kr
Red kR
Tawny red kr

However, another cross which involves the same color types gives a quite different result. The F_1 seed instead of being tawny buff in color is distinctly black. In the F_2 there are five color types coming out instead of the four types mentioned above, as follows:

P_1	F_1	F_2				
Red × korra buff	Black	Black	Tawny buff	Sepia	Red	Tawny red
		36	4	11	3	1

It clearly indicates, therefore, that the hypothesis of two complementary factors is not sufficient to explain such behavior. In this case, either the korra buff or the red type must have two different genotypes to start with. In order to test our hypothesis, natural hybrids involving tawny red and black and the blacks from the F_2 were planted. The results are shown in Table 2.

Difficulties are likely to arise in differentiating between the blacks and sepias. The mature grain of both types show very little, if any, difference, but the immature grain is distinctly different. Immature grain of the blacks is either tawny buff or korra buff in color, never otherwise; while that of the sepias is either red or tawny red.

TABLE 2.—*F_2 and F_3 progenies of a cross of red×korra buff and F_2 progenies of natural hybrids between tawny red and black.*

Pedigree	Pedigree	Black	Tawny buff	Korra buff	Sepia	Red	Tawny red
F_1 1–4	F_2 114	36	4	0	11	3	1
	F_3 282	39	14	2	4	2	1
	284	11	3	0	7	4	7
	286	32	7	3	2	2	0
	326	1	1	1	2	0	2
	331	14	6	2	11	1	3
	335	4	5	0	4	5	3
	341	12	5	1	3	0	1
	344	17	7	1	1	1	0
	345	20	10	2	3	3	2
	348	5	4	0	3	1	1
	350	18	3	2	8	0	2
	363	32	13	12	9	4	7
	368	25	6	4	12	0	4
	369	10	5	7	5	1	3
	372	15	8	0	4	2	4
Natural hybrid	F_2 109	28	8	6	8	1	1
	110	21	8	5	5	1	7
Observed		340	117	48	92	31	49
Calculated 27:9:12:9:3:4		285.39	95.13	126.84	95.13	31.71	42.28

P = less than 0.01

Rangaswami Ayyangar stated in 1934 that six grain colors have been observed in *Setaria italica*, as follows: (a) Black, tawny buff, and korra buff, and (b) sepia, red, and tawny red. A factor K is present in group (a) and absent in group (b). In each of these two groups, the basic colors tawny red and korra buff with the addition of a factor I turn into red and tawny buff. This red and tawny buff with the addition of another factor B turn into sepia and black, respectively. Factor B has an individuality, but its presence is not visible except in association with I. Since we do not have the original paper in which this work is reported, it is impossible to tell how these conclusions were arrived at.

From our results, it is clear that we have two kinds of korra buff types. When crossed with red, F_1 seeds are tawny buff in one case and black in another. When sepia, red, and tawny red are considered separately (Table 2), they fit a 9:3:4 ratio closely, denoting the presence of two genotypes in tawny red. This phenomenon is verified again in the segregating generation of sepia, as will be seen later. Attempts have been made to cross tawny reds with tawny buff. Theoretically, one cross will obtain tawny buff F_1, but with another genotype, the F_1 will be black instead. Unfortunately, we failed to obtain such crosses. Should there be two genotypes for korra buffs and also two for tawny reds, the six types as shown in Table 2 should fit a 27:9:12:9:3:4 ratio so they are assigned to the following genetic factors:

Type	Color	Factor	Type	Color	Factor
1	Black	KRB	4	Sepia	kRB
2	Tawny buff	KRb	5	Red	kRb
3a	Korra buff	KrB	6a	Tawny red	krB
3b	Korra buff	Krb	6b	Tawny red	krb

The observed results do not fit the theoretical expectation well enough, however, for the P value is less than .01. Table 2 shows an overwhelming surplus of the blacks and a great deficiency of the korra buffs. The four other types fit the expectation almost perfectly. We can offer no explanation for this, except that possibly the number is not yet big enough. Further studies are in progress.

In order to check the hypothesis further, intercrosses were made between different color types. The results of which are given in Table 3.

TABLE 3.—*F_2 progenies of the cross tawny buff×black.*

P_1		F_1		F_2		
Pedigree	Color	Pedigree	Color	Pedigree	Black	Tawny buff
13×1	Tawny buff×black	154–1	Black	237	14	8
13×1	Tawny buff×black	154–2	Black	238	4	7
5×1	Tawny buff×black	171–1	Black	252	3	3
5×1	Tawny buff×black	171–2	Black	253	5	0
5×1	Tawny buff×black	171–5	Black	256	7	9
		Observed			33	27
		Calculated 3:1			45	15
		Dif.			12±2.26	

BLACK (TYPE 1)×TAWNY BUFF (TYPE 2)

The results of these crosses involving types 1 and 2 do not fit the calculated expectation well enough. The small number in the progenies might offer a reasonable explanation for such a deviation. The observed results do fit a 9:7 ratio perfectly, however, and should such be the case, tawny buff would not be type 2 but type 3b and the F_2 segregation would give rise to three color types instead of two. The pedigree 5 seeds used as one of the parents, however, were decidedly tawny buff (type 2). When crossed with korra buff (type 3b), a 3:1 ratio is obtained, as will be seen later. Thus, we might conclude that black (type 1) is dominant over tawny buff (type 2) with a single mendelian segregation.

BLACK (TYPE 1)×KORRA BUFF (TYPE 3B)

From Table 4, it can be seen that when type 1 is crossed with type 3b, three color types in a ratio of 9:3:4 are obtained. The fit is rather close to the theoretical result even with such small numbers. P is between .02 to .01. It is unfortunate that type 3a is not involved in any of these crosses.

TABLE 4.—*F_2 progenies of the cross korra buff and black as well as the F_3 progenies from the blacks in the F_2 which segregate for these types.*

P_1		F_1		F_2			
Pedigree	Color	Pedigree	Color	Pedigree	Black	Tawny buff	Korra buff
3×2	Korra buff×black	175–1	Black	263	13	5	3
3×2	Korra buff×black	175–2	Black	264	16	6	0
3×2	Korra buff×black	175 3	Black	265	5	2	0
2×3	Black×korra buff	179–1	Black	267	12	10	1
			F_3	285	19	2	3
				297	8	2	1
			F_4	597	14	3	5
				598	6	1	3
			Observed		93	31	19
			Calculated 9:3:4		80.37	27.79	35.72

P = .02 to .01

BLACK (TYPE 1)×RED (TYPE 5)

From Table 5, it is clear that a 9:3:3:1 ratio is obtained when crosses are made between blacks and reds, indicating a two factor difference

TABLE 5.—*F_2 progenies of the cross black×red and the F_3 progenies of the blacks in the F_2 segregating for these types.*

P_1		F_1		F_2				
Pedigree	Color	Pedigree	Color	Pedigree	Black	Tawny buff	Sepia	Red
2×9	Black×red	180–4	Black	272	11	5	0	1
2×9	Black×red	180–1	Black	273	6	1	0	0
10×1	Red×black	164-1	Black	242	4	9	13	2
			F_3	280	40	23	2	0
				289	20	8	0	4
				294	17	6	2	2
				300	13	5	5	1
				328	1	3	1	1
				333	8	3	3	1
				334	6	7	4	2
				337	8	9	4	0
				339	22	11	5	0
				342	29	5	9	6
				343	4	2	14	0
				362	22	10	4	0
				364	49	2	15	1
				365	33	10	12	3
				367	25	12	8	1
				370	19	8	5	0
				373	10	7	7	5
				375	10	7	3	0
			Observed		353	144	103	27
			Calculated 9:3:3:1		352.7	117.57	117.57	39.19

P equals .01

between these types. Relatively small populations in the progenies might lead to a wrong classification. For instance, pedigrees 280 and 339 may not belong to the right classes, thus explaining the poor fit, P equals .01. Such deviation as does occur from random sampling would only be once in a hundred trials. Here in this case, the excess class is the tawny buff and the deficient class is the red. We may conclude, however, that type 1 and type 5 are different in K and B and are similar in both having R factor.

TAWNY BUFF (TYPE 2) × KORRA BUFF (TYPE 3B)

There is only one factor difference between these two types (Table 6). This involves the factor B. The observed results fit the calculated expectation very well. Theoretically, when type 2 is crossed with type 3a, the F_1 seeds should be black, but such a cross was not made.

TABLE 6.—*F_2 progenies of the cross tawny buff and korra buff.*

P_1		F_1		F_2		
Pedigree	Color	Pedigree	Color	Pedigree	Tawny buff	Korra buff
24×25	Tawny buff × korra buff	133-2	Tawny buff	212	31	13
5×6	Tawny buff × korra buff	172-1	Tawny buff	257	15	3
5×6	Tawny buff × korra buff	172-2	Tawny buff	258	13	4
5×6	Tawny buff × korra buff	172-3	Tawny buff	259	14	3
5×6	Tawny buff × korra buff	172-4	Tawny buff	260	7	10
				Observed	80	33
				Calculated 3:1	84.75	28.25

Dif. = 4.75 ± 3.10

TAWNY BUFF (TYPE 2) × RED (TYPE 5)

Tawny buff is different from red in the K factor only. The observed results (Table 7) fit the expected calculation almost too good for such a small population.

TABLE 7.—*F_2 progenies of the cross tawny buff × red.*

P_1		F_1		F_2		
Pedigree	Color	Pedigree	Color	Pedigree	Tawny buff	Red
5×10	Tawny buff × red	169-1	Tawny buff	247	18	5
5×10	Tawny buff × red	169-2	Tawny buff	248	16	6
				Observed	34	11
				Calculated 3:1	33.75	11.25

Diff. = 0.25 ± 1.96

TAWNY BUFF (TYPE 2)×TAWNY RED (TYPE 6B)

The F_2 population of this cross (Table 8) is too small to have a good fit. Nevertheless, the data indicate a two factor difference between these types. According to the hypothesis, if type 2 is crossed with type 6a, the resulting F_1 seeds would be black in color, but unfortunately, attempts to make this cross were without success.

TABLE 8.—*F_2 progenies of the cross tawny buff×tawny red.*

P_1		F_1		F_2				
Pedigree	Color	Pedigree	Color	Pedigree	Tawny buff	Korra buff	Red	Tawny red
20×9	Tawny red × tawny buff	145-1	Tawny buff	222	4	7	1	3
				Calculated	9	3	3	1

KORRA BUFF (TYPE 3A OR 3B)×TAWNY RED (TYPE 6A OR 6B)

Most probably only the b type is involved in each of these cases.

The observed results (Table 9) fit the theoretical expectation perfectly. We may conclude, therefore, that there is only one factor difference (Kk) between these two types (3a and 6b). Crosses involving 3a and 6b or 3b and 6a were not met with in our experiment.

TABLE 9.—*F_2 progenies of the cross korra buff and tawny red.*

P		F		F		
Pedigree	Color	Pedigree	Color	Pedigree	Korra buff	Tawny red
20×25	Tawny red×korra buff	137-1	Korra buff	217	14	7
20×25	Tawny red×korra buff	137-2	Korra buff	219	21	8
20×25	Tawny red×korra buff	137-5	Korra buff	221	19	4
20×25	Tawny red×korra buff	137-3	Korra buff	223	6	1
				Observed	60	20
				Calculated 3:1	60	20
					Diff. = 0	

F_3 and F_4 progenies of sepia segregating for sepies, reds, and tawny reds are shown in Table 10.

From Table 10, it can be seen that the tawny reds have two genotypes. The observed results fit a 9:3:4 ratio very closely, with P between .95 and .90.

In order to test the hypothesis still further, the genotypes of F_2 of the various crosses were identified by observing their mode of segregation in the F_3 generation. In the cross, red and korra buff, the following genotypes should appear in the F_2:

Genotypes	Observed	Calculated 1:2:2:4:1:2:1:2:1
KKRR	3	4.4
KKRr	4	8.8
KkRR	14	8.8
KkRr	12	17.6
KKrr	5	4.4
Kkrr	10	8.8
kkRR	8	4.4
kkRr	10	8.8
kkrr	4	4.4
	70	70.4

P = .20

The frequency of the occurrence of the genotypes fits rather closely with the theoretical expectation. Such deviations as occur by chance would be once in five trials, P = .2

TABLE 10.—*F_3 and F_4 progenies of sepia.*

Pedigree	Sepia	Red	Tawny red
	F_3		
354	24	10	15
355	15	7	4
356	8	3	4
357	19	6	10
358	21	5	10
359	16	6	4
	F_4		
609	21	1	2
610	12	1	1
611	8	1	7
Observed	144	40	57
Calculated 9:3:4	135.54	45.18	60.24

P = .95 to .90

In the cross korra buff (type 3a) and red (type 5), the blacks in the F_2 should have the following genotypes:

Genotypes	Observed	Calculated 1:2:2:2:4:4:4:8
KKRRBB	7	2.7
KKRRBb	10	5.4
KKRrBB	4	5.4
KkRRBB	8	5.4
KKRrBb	4	10.8
KkRrBB	7	10.8
KkRRBb	18	10.8
KkRrBb	15	21.6
	73	72.9

P = less than .01

A poor fit is obtained between the observed and the calculated results. Such deviations by chance would occur less than once in a hundred trials. Since many of the populations in the F_3 families are too small, wrong classifications are likely to result, hence the poor fit.

When the sepias in the F_2 of the above cross were planted, the genotypes as presented below should be obtained:

Genotypes	Observed	Calculated 1:2:2:4
kkRRBB	6	2.33
kkRRBb	0	4.66
kkRrBB	4	4.66
kkRrBb	11	9.32
	21	20.97

P = between .02 and .01

The fit is not so good. The kkRRBb class is not obtained at all. Probably the explanation is that the number of families is rather small and the number in many of the families is too small for a correct classification.

From the data presented above it seems that the assumption of the interaction of three factors, K, R, and B, for the appearance of the six phenotypes in the seed coat color of foxtail millet is correct. It agrees closely with the hypothesis of Rangaswami Ayyangar and his co-workers. K and R are complementary factors. B is a supplementary factor, its presence being detected only when R is present. (R is the same as I of Rangaswami Ayyangar, the change being obvious from the data presented.) However, there are still some loopholes in the mode of inheritance for the blacks, tawny buffs, and korra buffs, that is, those with factor K. The data presented for their genetic behavior are too inconclusive. Further studies are necessary for their elucidation and are in progress.

ENDOSPERM CHARACTERS

WAXY VS. NON-WAXY

Waxy endosperm is frequently found in the cultivated foxtail millet. It is chiefly used in the making of pastry and wine. Like the glutinous rice, it is not grown extensively except for special purposes. Li[5] found that this character is inherited in a simple Mendelian fashion. It is recessive to its normal allele, the non-waxy type. The waxy character is easily identified by either macroscopic examination or by the simple iodine solution test as in the case with Zea, sorghum, pro-millet, etc. Further data on the inheritance of this character are presented in Table 11.

From Table 11, we can see that non-waxy and waxy endosperms are determined by a single gene, Wx and wx. The excess in the waxy class may be the result of faulty classification on account of the minuteness of the grains, or due to some other reason which is yet to be detected.

[5]Loc. cit.

TABLE 11.—*Segregation of non-waxy and waxy endosperm in the F_2 progenies.*

P_1		F_1		F_2	
Pedigree	Character	Pedigree	Character	Non-waxy	Waxy
21×10	wx. × wx.	135–1	Wx	263	107
21×10	wx. × wx.	135–2	Wx	239	91
20×25	wx. × wx.	137–1	Wx	263	111
20×25	wx. × wx.	137–2	Wx	218	67
20×25	wx. × wx.	137–3	Wx	120	53
20×25	wx. × wx.	137–4	Wx	132	45
20×25	wx. × wx.	137–5	Wx	149	51
20×25	wx. × wx.	137–6	Wx	127	61
13×20	Wx × wx	155-1	Wx	372	132
3×20	Wx × wx	173–1	Wx	165	74
2×11	Wx × wx	181–1	Wx	607	256
20× 9	wx × Wx	145-1	Wx	561	224
			Observed	3,216	1,272
			Calculated 3:1	3,336	1,112

Difference = 150±19.6

YELLOW VS. WHITE ENDOSPERM

Most of the cultivated foxtail millets have yellow-colored endosperm. Some varieties, however, have white endosperm. The results of a cross involving these color types is shown in Table 12.

TABLE 12.—*F_2 progeny of the cross of white and yellow endosperm.*

P_1		F_1		F_2	
Pedigree	Character	Pedigree	Character	White	Yellow
20×9	White×yellow	145–1	White	587	198
			Calculated 3:1	588.75	196.25

Diff. = 1.75±8.18

From the data presented in Table 12, we can conclude that endosperm color is determined by a single pair of allelomorphic genes, Ww. Waxy endosperm is also involved in the same cross. An independent segregation is obtained for these two factors, as shown in Table 13.

TABLE 13.—*F_2 progeny of a cross when Wx, wx, and Ww are involved.*

P_1		F_1		F_2			
Pedigree	Cross	Pedigree	Character	W Wx	W wx	w Wx	w wx
20×9	W wx×w Wx	145–1	W Wx	427	160	134	64
			Calculated 9:3:3:1	441.54	147.18	147.18	49.06

P = 0.1–0.05

EARHEAD CHARACTERS

PALMATIC VS NORMAL EARHEAD

The earhead of the cultivated foxtail millet is characterized by having a main axis with many side branches (Fig. 1). The spikelets substending by bristles are borne on the lateral branches. There are many varieties of millet whose earhead is cylindrical in form, that is, the branches on the main axis are more or less equal in length throughout. However, there are several varieties in our collection with a palmatic type of head. The branches on the main axis gradually lengthen out from the tip of the axis downward. Sometimes the lower branches are about as long as the head itself, although of course, the number of branches of this extreme type is much less than in the normal type. As a result, the head resembles more or less a palm. In fact, the local name of such a variety is "monkey's hand."

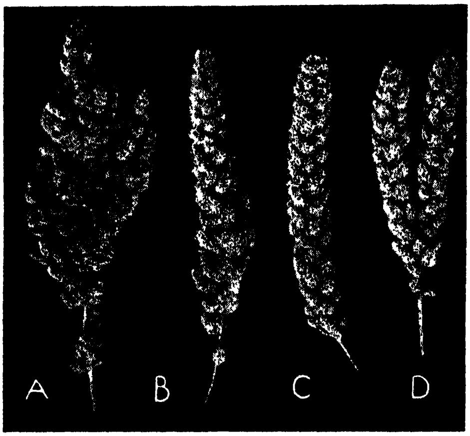

FIG. 1.—Variation in form of head of millet. A, palmatic form; B, palmatic form in a segregating generation, this type not apt to segregate again; C, normal head; D, double head.

When the palmatic type is crossed with the normal type, the F_1 is palmatic (Table 14), but this is rather intermediate in type. That is to say, the length of the branches is not as long as that of the typical palmatic type, and the number of branches is also intermediate between the normal and the palmatic type.

TABLE 14.—*F_2 progenies of a cross between palmatic and normal type of earhead.*

P_1		F_1		F_2		
Pedigree	Character	Pedigree	Character	Pedigree	Palmatic	Normal
24×34	Palmatic×normal	131–3	Palmatic	208	20	20
24×34	Palmatic×normal	131–5	Palmatic	210	23	13
24×25	Palmatic×normal	133–1	Palmatic	211	23	24
24×25	Palmatic×normal	133–2	Palmatic	212	18	16
			Observed		84	73
			Calculated	9:7	88.29	68.67

Diff. = 4.33±4.19

The F_2 progenies were grown in the breeding garden of the National Wuhan University. As stated before, the soil and weather were not suitable for a normal crop of millet. As a result, the heads were rather deformed so that the classification was doubtful. In order to check upon this, F_3 progenies were grown. As the F_3 crop was grown at Chengtu, an ideal place for millet growing, classification was thus made easy, so the correction can be made according the mode of segregation. When the F_2 population is thus corrected, it fits a 9:7 ratio rather closely, even though the number is small. Hence, a duplicate factorial hypothesis is assumed. The palmatic type must have both P_1 and P_2 present. Either a single dominant dose or nil will result in normal type. In order to check upon this hypothesis further, the F_3 segregation will reveal the genotypes of the palmatic types in the F_2 as follows:

Genotypes	Observed	Calculated 1:2:2
$P_1P_1P_2P_2$	13	9.33
$P_1P_1P_2p_2$ $P_1p_1P_2P_2$	15	37.32
$P_1p_1P_2p_2$	56	37 32

P = less than 0.01

As the number of the F_3 progenies is none too big, mostly around 50, the classification may be erroneous. Thus the fit is none too good, but it indicates strongly that our hypothesis is correct. The F_4 generation was grown in 1939 and the segregation checked rather closely with the above hypothesis.

NORMAL VS. DOUBLE EARHEAD

In several of the F_3 progenies of the cross involving palmatic and normal earhead, some double heads were noticed, but none had been found in the previous generation. The double heads have two normal earheads attached to a single shoot. Most of them are attached near the basal branch but sometimes they are connected at the middle of

TABLE 15.—*F_3 families segregate for double earhead.*

Pedigree	Normal	Double
439	63	1
446	56	1
441	75	1
450	70	1
454	85	2
458	61	2
Observed	410	8
Calculated 63:1	411.39	6.53
464	74	5
Calculated 15:1	73.95	4.93

the axis. Still others may branch out near the tip of the earhead, but, the latter type is infrequent (Fig. 1).

Since the double earheads apparently appear in a definite proportion of the population in a segregating progeny and since they seem to be inherited, the families in the F_3 which segregate for the normal and double earhead types are shown in Table 15.

If the double earhead type is inherited, a triple factor hypothesis should be assumed. It must be represented by the triple recessive and this must breed true in the following generation. Unfortunately, in planting the seeds from such a head, not a single double earhead was obtained. Thus, it is clear, that this is a chance variation and not inherited.

SUMMARY

Six color types for the seed coat of foxtail millet have the following factorial assignment:

Black	KRB
Tawny buff	KRb
Korra buff	KrB
	Krb
Sepia	kRB
Red	kRb
Tawny red	krB
	krb

Endosperm characters are all controlled by simple Mendelian factors, as follows:

Wx	non-waxy	wx	waxy
W	white	w	yellow

wx and w are inherited independently.

Earhead types may be palmatic or normal and are controlled by duplicate factors, P_1 and P_2, as follows:

9	P_1P_2	palmatic
	P_1p_2	
7	p_1P_2	normal
	p_1p_2	

Double earheads are not inherited.

A DIVISION OF THE ALFALFA CROSS-INOCULATION GROUP CORRELATING EFFICIENCY IN NITROGEN FIXATION WITH SOURCE OF *RHIZOBIUM MELILOTI*[1]

JOE C. BURTON AND LEWIS W. ERDMAN[2]

A SYMBIOTIC nitrogen-fixation relationship between leguminous plants and *Rhizobia* is known to be dependent upon the plant as well as the root nodule bacteria. The qualities or requisites for either have as yet been undefinable from a biochemical or physiological standpoint. Studies to date have dealt primarily with demonstrations of the phenomenon and the extent of its existence within the plant groups.

Previous studies have shown that a strain of bacteria efficient in nitrogen fixation on one leguminous plant within a cross-inoculation group is not necessarily efficient on other plants in the same group. They have also shown that there are all gradations in efficiency among strains of legume bacteria causing nodule formation on any one host plant. These studies demonstrate a group specificity with respect to the legume bacteria isolated from alfalfa (*Medicago sativa*) and sweet clover (*Melilotus* sp.), and their nitrogen fixation efficiency on burr clover (*Medicago hispida, arabica*) and fenugreek (*Trigonella Foenum-Graecum*), which belong to the same cross-inoculation group. When all, or the majority of all, strains of bacteria isolated from a particular leguminous plant fail to cause nitrogen fixation, although producing excellent nodulation on another plant within the same group, it reflects a change in the bacteria produced by the physiology or the chemistry of the plant itself. This phenomenon is demonstrated in these studies with *R. meliloti* isolated from alfalfa and sweet clover. It can not be demonstrated with strains of *R. meliloti* isolated from burr clover or fenugreek on the plants now included in the alfalfa cross-inoculation group.

HISTORICAL

A complete review of the literature up to 1932 showing strain differences in nitrogen-fixation efficiency and the part which the host plant plays in a symbiotic relationship is presented by Fred, Baldwin, and McCoy (5)[3] and also by Allen and Baldwin (1). Since then there have been a number of papers emphasizing the importance of the host plant in a bacteria-plant relationship. Bjalfve (2) found differential response among the vetches as to the number and position of the nodules and quantity of nitrogen fixed. Virtanen and Hausen (6) found that the most suitable strains of organism for one variety of peas was likewise the best for other varieties. In their studies, however, only two strains of the nodule organisms were used, hence the observation may be true for these two strains. It was proved not to be true when a larger number of strains were used by Erdman and Burton (4) in 1938. There was a marked differential response with respect to

[1]Contribution from Research Laboratory, The Nitragin Company, Inc., Milwaukee, Wis. Received for publication March 19, 1940.

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[3]Figures in parenthesis refer to "Literature Cited," p. 450.

variety when eight strains of *R. leguminosarum* were tested for efficiency on four varieties of peas.

In 1937, Wilson, Burton and Bond (7) demonstrated an effect of species of host plant on nitrogen fixation in *Melilotus*. Because of the significance of the occurrence of this specificity of the host plant in the symbiotic nitrogen-fixation system from both a theoretical and practical point of view, these investigations were extended to the *Medicago*.

In 1939, Burton and Wilson (3) reported results obtained when three varieties of *Medicago* (Ladak, Hairy Peruvian, and Grimm) were tested for ability to fix nitrogen in association with nine strains of *R. meliloti*. The same nine strains of *Rhizobia* were also tested for nitrogen-fixation ability using five species of *Medicago* (*M. sativa, M. arabica, M. hispida, M. lupulina*, and *M. minima*). There was a definite host plant specificity among the five species of *Medicago*; however, the specificity among the three varieties of alfalfa was much less than that among the different species. In these studies only one strain of *R. meliloti* caused any appreciable nitrogen fixation on *M. hispida* or *M. arabica* which are two species of burr clover. This strain was isolated from alfalfa plants grown in a jar of sterile sand in the greenhouse and the source of bacteria was ripened burrs taken from burr clover plants and implanted with the sterile sand. This finding led to the present studies to find the cause of the high specificity demonstrated by burr clover.

METHODS

Essentially the same technic was used as described in previous publications (4, 7). Disinfected seeds were planted in jars containing sterilized sand and all the known necessary plant food elements except nitrogen. Triplicate jars were inoculated with each strain of the nodule organism at the time of planting. The plant cultures were grown in a thermostatically controlled greenhouse kept at 70° to 75° F and were supplied artificial light during extreme periods of cloudy weather. Bryan's modification of Crone's nutrient solution was added at 2-week intervals. Sterile distilled water was added as needed. The plants were grown for 60 to 90 days, the entire plant then being harvested, dried, and nitrogen analyses made, using the Kjehldahl apparatus.

EXPERIMENTAL

In a preliminary experiment during the fall of 1937, six strains of *R. meliloti* which were isolated from burr clover were used to inoculate two species of burr clover (*M. arabica* and *hispida*) growing in the same jars. The sources of all strains of the nodule bacteria used in these experiments are presented in Table 1. Growing conditions were extremely favorable and the nitrogen fixation by three strains was very high. The three other strains caused no significant increase in total nitrogen over the controls. The nitrogen-fixation data are presented graphically in Fig. 1.[4]

The nodulation produced by one of the highly effective strains is compared (Fig. 2) with that produced by one of the ineffective strains. The marked degree of specificity in this preliminary experiment led us to plan a second experiment using strains of *R. meliloti* isolated

[4]Each column in the graphs presented in this paper represents the average for three replicate plant cultures. Because of the length of the paper and the consistent agreement between replicates, the individual data are omitted.

from alfalfa, burr clover, and sweet clover to inoculate alfalfa, burr clover, sweet clover, and fenugreek, all of which belong to the same cross-inoculation group, in order to find some explanation for the marked specificity. Details of experiments 2 and 3 are as follows:

Experiment 2.—Twenty strains of *R. meliloti*, 8 of which were isolated from alfalfa, 7 from burr clover, and 5 from sweet clover, were used to inoculate alfalfa, sweet clover, burr clover, and fenugreek. The planting was made on Oct. 15 and the plants were harvested on Dec. 10. Triplicate jars were planted to each bacterial treatment. The growth conditions were quite satisfactory.

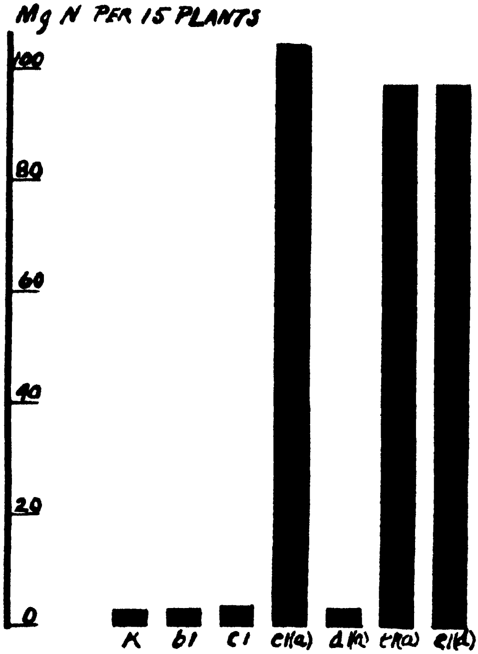

FIG. 1.—Nitrogen fixation by burr clover inoculated with six strains of *R. meliloti* from burr clover.

Experiment 3.—In this experiment 20 strains of *R. meliloti*, 6 isolated from alfalfa, 4 from sweet clover, 6 from burr clover, 3 from fenugreek, and 1 from bitter clover (*Melilotus indica*), were used to inoculate alfalfa, burr clover, and fenugreek. Planting was made on Feb. 10, 1939. The weather was cloudy during a large part of the time and mazda lamps were used to supplement the lighting. These unfavorable conditions, however, were not entirely undesirable because it gave opportunity to study the same phenomenon under different environmental conditions.

RESULTS

The data show two types of host plant specificity, *viz.*, (a) a specificity with respect to nitrogen fixation occurring when a strain of the legume bacteria invades the roots forming nodules on different species or varieties of legumes included in a common cross-inoculation group, and (b) a group host-plant specificity or non-symbiotic relationship with all *Rhizobia* isolated from other species included in the same bacteria-plant group. The former type has been discussed in previous publications and will not be discussed here except to illustrate the two types of response to strains of the legume bacteria.

The responses of alfalfa, sweet clover, and burr clover to *Rhizobia* isolated from these three legumes are given in Figs. 3, 4, and 5. In general, alfalfa responded well to alfalfa, sweet clover, and burr clover organisms, sweet clover to alfalfa, sweet clover, and burr clover organisms, and burr clover only to burr clover bacteria. The

TABLE 1.—*Sources of Rhizobium meliloti used for artificial inoculation of plants.*

Culture No.	Legume source	State	Year
3DOa1	*Medicago*	Wisconsin	1912
3DOa2	*Medicago sativa*	Wisconsin	1938
3DOa3	*Medicago sativa*	Wisconsin	1938
3DOa7	*Medicago sativa*	Minnesota	1932
3DOa10	*Medicago sativa*		1926
3DOa12	*Medicago sativa*		1928
3DOa14	*Medicago sativa*	Idaho	1928
3DOa15	*Medicago sativa*	Minnesota	1932
3DOa17	*Medicago sativa*	Minnesota	1932
3DOa26	*Medicago sativa*		1931
3DOc1	*Medicago arabica*	Mississippi	1937
3DOc1 (a)	*Medicago arabica*	Mississippi	1937
3DOc2	*Medicago arabica*	Mississippi	1937
3DOc3	*Medicago arabica*	South Carolina	1938
3DOc4	*Medicago arabica*	South Carolina	1938
3DOe1 (a)	*Medicago hispida*	Alabama	1937
3DOe1 (c)	*Medicago hispida*	Alabama	1937
3DOe1 (d)	*Medicago hispida*	Alabama	1937
3DOe2	*Medicago hispida*	North Carolina	1939
3DOd1 (a)	*Medicago hispida*		1928
3DOd2	*Medicago hispida*	California	1938
3DOb1	*Medicago lupulina*	Alabama	1936
3DOh3	*Melilotus alba*		1927
3DOh7	*Melilotus alba*	Michigan	1937
3DOh8 (a)	*Melilotus alba*	Alabama	1937
3DOh10	*Melilotus alba*		1937
3DOi3	*Melilotus officinalis*	Wisconsin	1938
3DOz1	*Melilotus indica*		1937
3EOf1	*Trigonella Foenum-Graecum*		1938
3EOf2	*Trigonella Foenum-Graecum*	Pennsylvania	1938
3EOf2 (b)	*Trigonella Foenum-Graecum*	Pennsylvania	1938

nodulation in every case was abundant; however, the alfalfa and sweet clover *Rhizobia* produced numerous, scattered nodules on burr clover. This is the type generally considered ineffective. That this was true is illustrated graphically by Figs. 6 and 7 which give the results of the nitrogen analyses on this experiment with alfalfa and sweet clover strains of *R. meliloti*.

Not one of the strains caused any significant nitrogen fixation on burr clover, although all strains except 3DOa26, which has consistently been parasitic on all the legumes in this group, caused considerable fixation on alfalfa and sweet clover.

The nitrogen fixation with burr clover strains shown in Fig. 8 illustrates only one type of specificity, e.g., specificity with an individual strain. 3DOe1 (d) and 3DOd2 are effective on all three host plants, while 3DOc1 is effective only for alfalfa.

In the same experiment (No. 2, Oct. 15 to Dec. 10, 1938) fenugreek was inoculated with seven of the same strains of *R. meliloti*. The results are given in Fig. 9.

Fenugreek demonstrates a similar non-symbiotic association with the *Rhizobia* from alfalfa and sweet clover to that of burr clover. Strains 3DOe1 (d) and 3DOc2 from burr clover fixed about 70 mg of nitrogen per 10 plants, while the other strains showed no significant

FIG. 2.—Nodulation produced by a highly effective and ineffective strain of *R. meliloti* on burr clover. *Right*, good strain; *upper left*, parasitic strain.

difference over the uninoculated control Nodulation was abundant with all strains.

In experiment 3 (Feb. 10, to April 17, 1939) 20 strains of *R. meliloti*, including some recently isolated alfalfa and fenugreek organisms, were tested for nitrogen-fixation efficiency on alfalfa, burr clover, and fenugreek. Although the growing conditions were poor because of excess cloudy weather, the results confirmed the findings of the previous experiment. Fenugreek responded well to burr clover and fenugreek strains but failed to grow at all when inoculated with alfalfa and sweet clover isolations.

The fenugreek bacteria caused high nitrogen-fixation on burr clover as well as alfalfa and sweet clover, thus placing this legume in the same group with burr clover as to its specific bacterial requirements and response. The strains highly effective on fenugreek are usually highly effective on burr clover.

Nitrogen analyses of experiment 3 are represented graphically in Figs. 10 and 11. The same non-symbiotic relationship of the alfalfa and sweet clover bacteria with fenugreek was again confirmed in this study.

DISCUSSION

The results of the foregoing experiments only emphasize the complex relationship of the root nodule bacteria with leguminous plants

resulting in biological fixation of atmospheric nitrogen. The consistent failure of the legume bacteria isolated from alfalfa and sweet clover in causing nitrogen fixation on burr clover and fenugreek suggests two possibilities. Either the two latter plants are much more specific in their bacterial requirements than the former two, or the legume bacteria are actually changed through association with alfalfa and

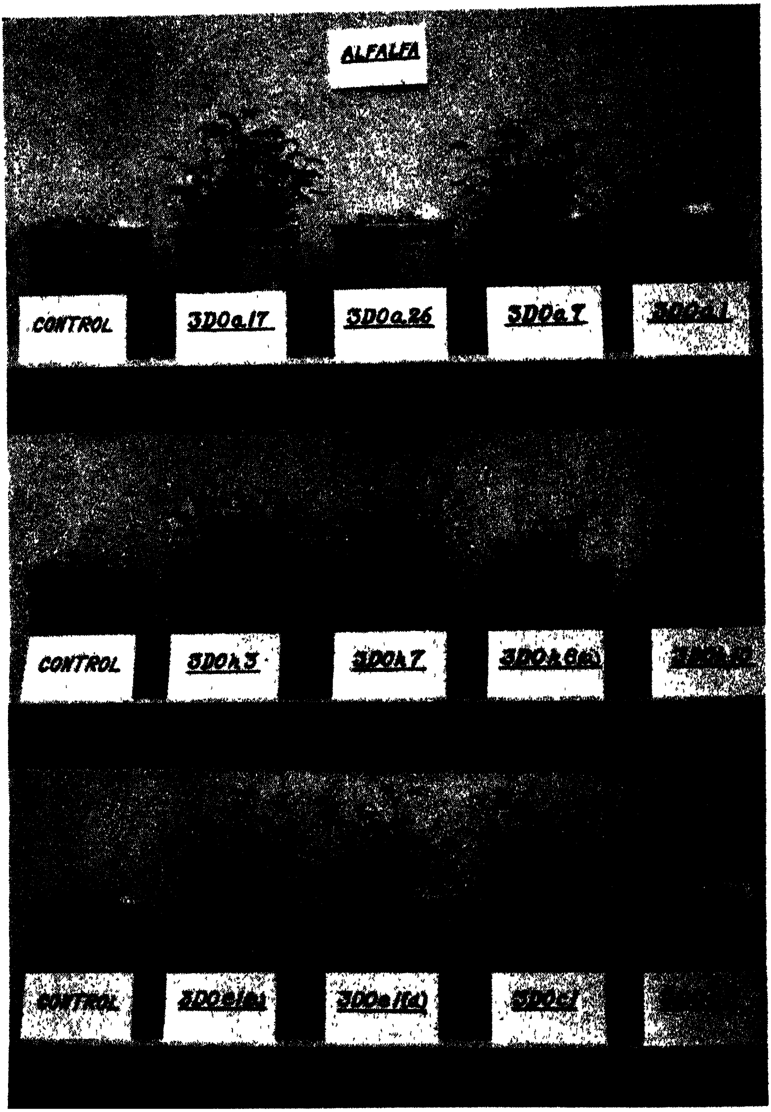

Fig. 3.—Alfalfa inoculated with *R. meliloti* from three sources. *Top*, alfalfa; *center*, sweet clover; *bottom*, burr clover.

sweet clover. If it is purely a question of host-plant specificity, then we must assume that the mechanism of nitrogen-fixation effected by alfalfa and sweet clover is different form that of burr clover and fenugreek inasmuch as nodulation occurred with all strains. However, since burr clover and fenugreek isolations also cause nitrogen-fixation on alfalfa and sweet clover as well as their mother host plant,

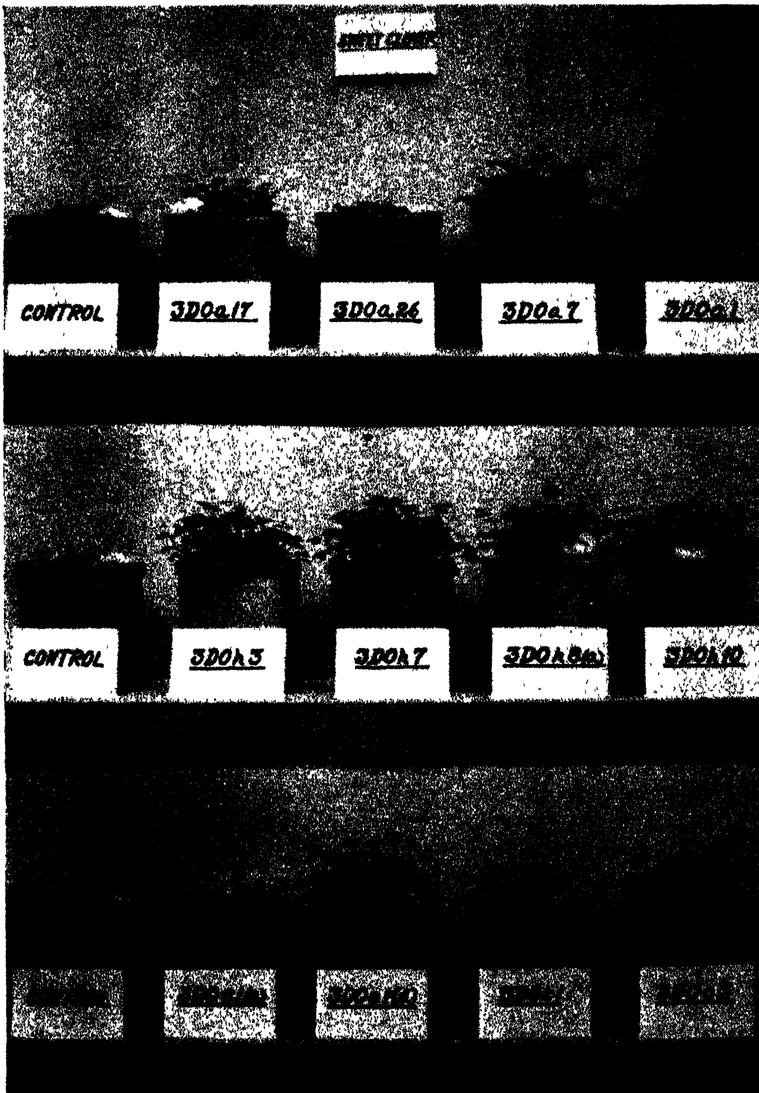

FIG. 4.—Sweet clover inoculated with *R. meliloti* from three sources. *Top*, alfalfa; *center*, sweet clover; *bottom*, burr clover.

it would seem that two mechanisms of fixation were not involved and that the bacteria had actually changed through association with alfalfa and sweet clover. In this case one would be led to believe that alfalfa and sweet clover plants, unlike burr clover and fenugreek, produce some component of fixation which results in the bacteria still being able to function efficiently on alfalfa and sweet clover, although

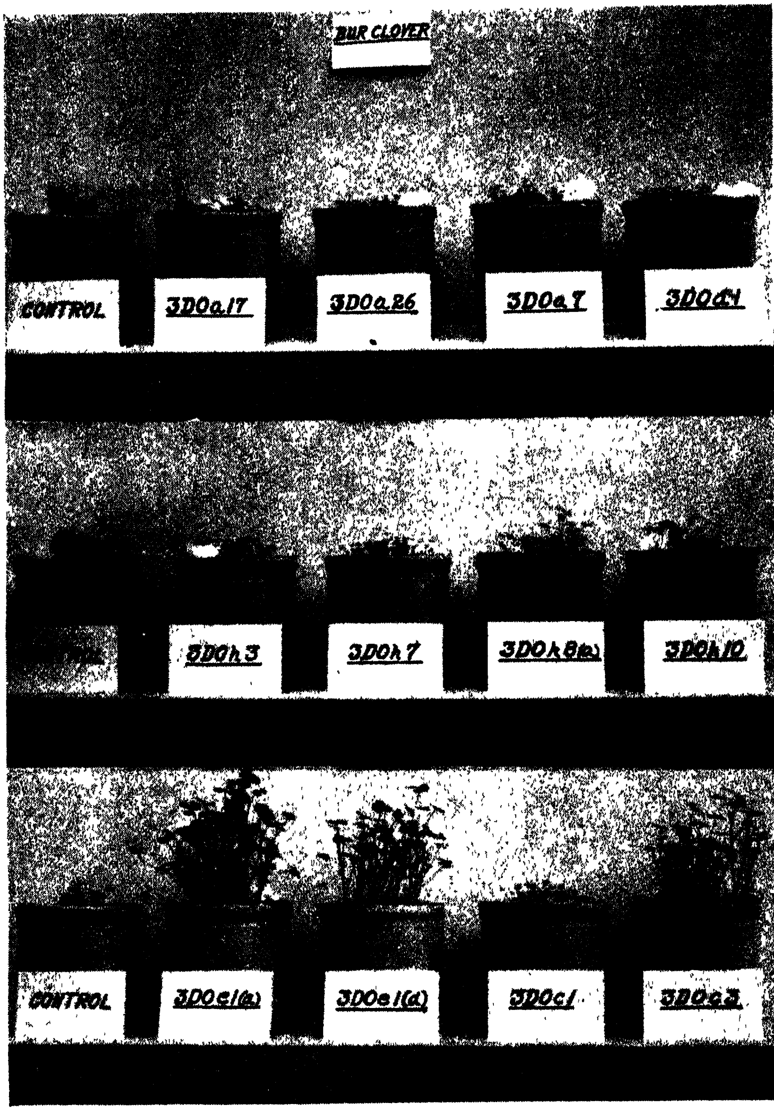

FIG. 5.—Burr clover inoculated with *R. meliloti* from three sources. *Top*, alfalfa; *center*, sweet clover; *bottom*, burr clover.

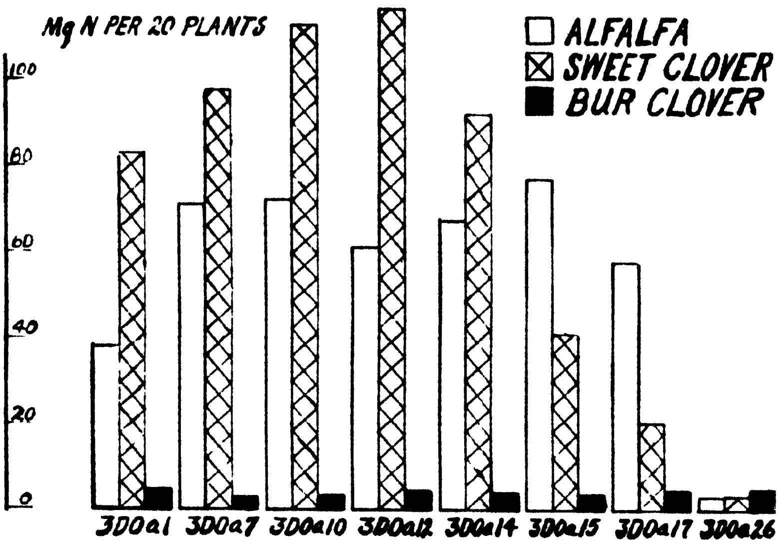

FIG. 6.—Nitrogen fixation produced by eight strains of *R. meliloti* isolated from alfalfa.

burr clover and fenugreek, being dependent upon the bacteria furnishing this component, are not able to fix nitrogen with strains of the nodule-organism which have been associated with alfalfa and sweet clover.

In these studies over a period of three years, 30 strains of *R. meliloti* have been tested for efficiency on the plants included within the alfalfa cross-inoculation group and without an exception the strains of bacteria isolated from alfalfa and sweet clover have failed to cause any nitrogen fixation on burr clover and fenugreek. We do not believe that strains of the bacteria which will be efficient nitrogen fixers on burr clover and fenugreek can not be isolated from alfalfa and sweet clover, but from these studies we have been led to believe that these bacteria upon repeated association with alfalfa or sweet

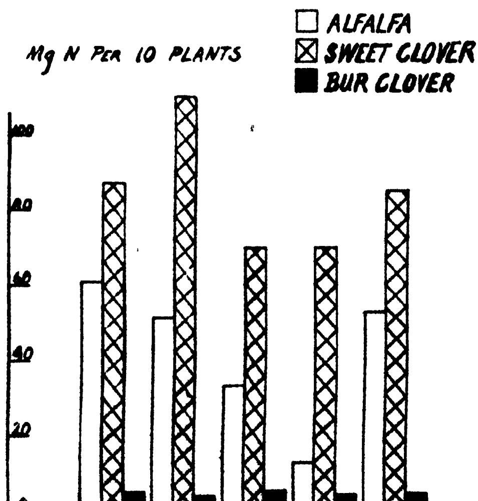

FIG. 7.—Nitrogen fixation produced by five strains of *R. meliloti* isolated from sweet clover.

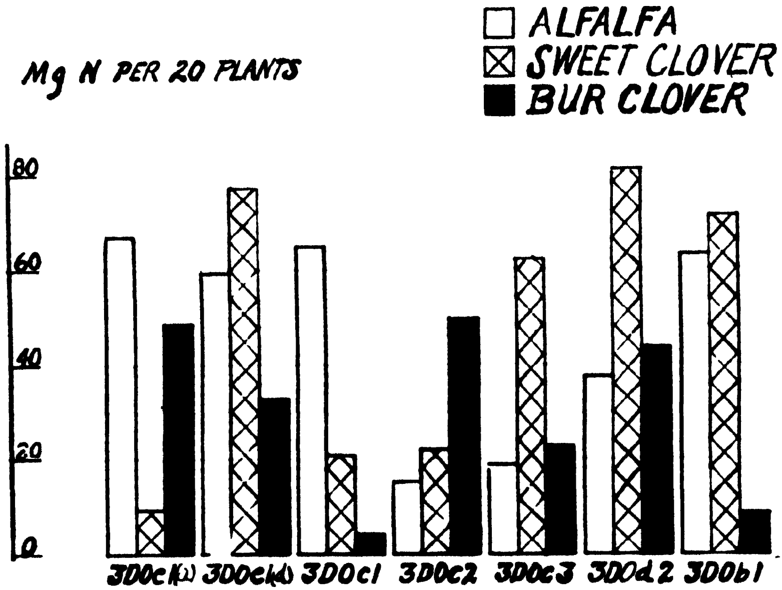

FIG. 8.—Nitrogen fixation produced by seven strains of *R. meliloti* isolated from burr clover.

clover soon lose their effectiveness on burr clover and fenugreek. Physiological studies have failed to reveal any noticeable differences between strains of the legume bacteria from different host plants. There are varying degrees of acidity in litmus milk, but this is true for the organisms from each host plant and there is no positive correlation between acidity and nitrogen fixation with any of the strains used on any of the host plants.

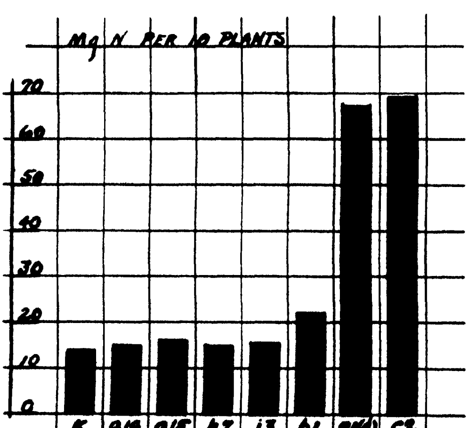

FIG. 9.—Nitrogen fixation by seven strains of *R. meliloti* on Fenugreek (*Trigonella Foenum-Graecum*).

Further study on the chemistry or physiology of the two groups of plants and also studies to determine if this hypothetical change in the bacteria is reversible would be interesting from the standpoint of the mechanism of biological nitrogen fixation.

From the practical standpoint these studies emphasize the necessity of using strains of the nodule bacteria isolated from burr clover and fenugreek for the successful inoculation of these legumes. They also stress the need of

more data on the performance of strains of bacteria from the nodules of each plant in a group on all legumes included in the same bacterial plant group.

SUMMARY AND CONCLUSION

Nitrogen-fixation studies of strains of *R. meliloti* on alfalfa, burr clover, sweet clover, and fenugreek revealed that the organism

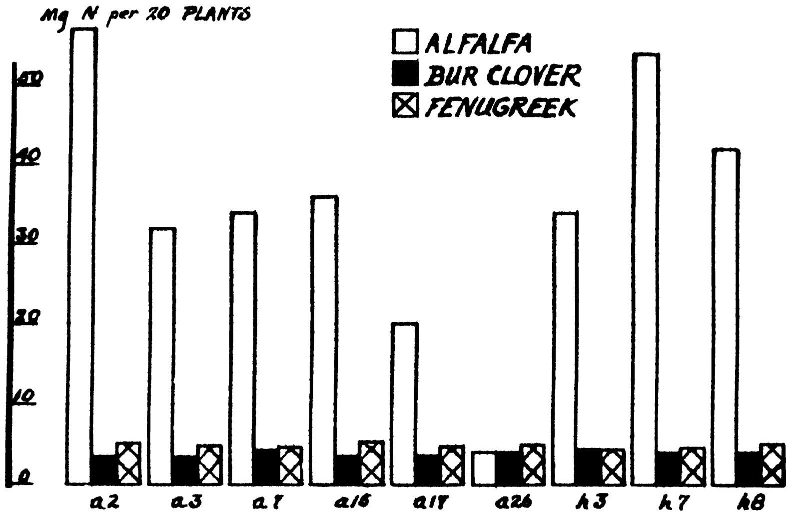

FIG. 10.—Nitrogen fixation by *R. meliloti* isolated from alfalfa and sweet clover.

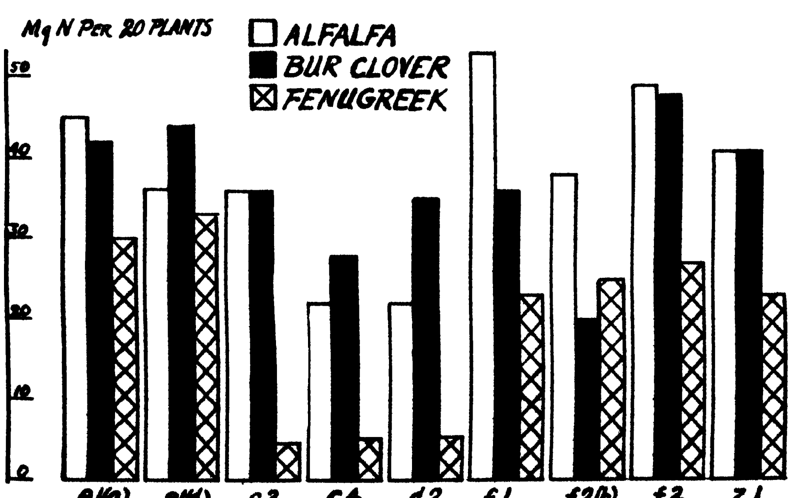

FIG. 11.—Nitrogen fixation by *R. meliloti* isolated from burr clover and fenugreek.

isolated from alfalfa and sweet clover failed to cause any significant fixation on burr clover or fenugreek. The strains of the bacteria isolated from burr clover or fenugreek showed an average percentage effective on all four host plants.

It was concluded that the bacteria living in association with alfalfa and sweet clover lose some component not necessary for high nitrogen fixation on these legumes but which is very necessary for fixation with burr clover and fenugreek. The nodule-forming capacity of the legume bacteria is not altered by association with any of the legumes studied.

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RELATIONSHIPS BETWEEN SOME MEASURES OF MATURITY IN MAIZE[1]

Ralph O. Snelling and Irwin R. Hoener[2]

A STUDY of four methods of measuring maturity in maize was made in 1939. A planting of 218 strains and hybrids in a cooperative insect resistance project at McClure, in extreme southern Illinois, was used. The 218 entries consisted of 68 inbred lines, 125 single crosses, and 25 double crosses.

Data were obtained upon the number of days from planting to silking, the percentage of plants with husks bleached or showing a dry appearance on September 5, and the percentage of dry matter in the grain on September 14 and again at harvest on October 12. The silking date was recorded as the time at which 50% of the plants in the plot showed emerged silks. The percentage of plants with bleached husks was obtained by counts of plants with husks showing a dry yellowish appearance. The percentage of dry matter in the grain on September 14 was determined by the official A.O.A.C. method. Samples were obtained by removing a portion of the kernels from the middle section of 10 ears of each entry, from plants that appeared to have about average maturity. The percentage of moisture at harvest on October 12 was determined with the Tag-Heppenstall apparatus on a representative sample of shelled corn.

The data presented here were obtained from single plots of each entry. The inbred plots were single rows 10 hills long, while the single crosses and double crosses were in two-row plots, 10 hills long. Each of the three groups of material was grown in separate blocks arranged so as to minimize the effects of soil heterogeneity. The block of single crosses with 125 entries occupied an area 50 hills square.

The entries differed appreciably in their seasonal requirements, the range in number of days from planting to 50% silking being 56 to 75 days for the inbred lines, 54 to 69 days for the single crosses, and 60 to 69 days for the double crosses. The percentage of plants with bleached husks on September 5 varied from 0 to 100% for both the inbred lines and the single crosses, while the double crosses ranged from 3 to 69%.

The percentage of dry matter in the grain on September 14 ranged from 52 to 87 for the inbred lines, 55 to 84 for the single crosses, and 55 to 71 for the double crosses. The range in the percentage of dry

[1]Cooperative investigation between the Illinois Agricultural Experiment Station, Illinois Natural History Survey, Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication April 4, 1940.

[2]Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Assistant in Soil Fertility, Department of Agronomy, Illinois Agricultural Experiment Station, respectively. Acknowledgment is due Ralph A. Blanchard, Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture, and John H. Bigger, Illinois Natural History Survey, for obtaining portions of the data correlated here.

matter on October 12 was 76 to 90 in inbred lines, 81 to 90 in single crosses, and 83 to 88 in double crosses.

In Table 1 are given the coefficients of correlations computed among the different measures of maturity. In general, the correlations were highest in the single crosses and lowest in the double crosses. The correlations computed between silking date and percentage of plants with bleached husks on September 5 in the inbred lines and the single crosses were negative and highly significant. The coefficient of −0.415 in the double crosses was below the 1% level, but above the 5% level of significance.

TABLE 1.—*Correlations between different measures of maturity of inbred lines, single-cross, and double-cross hybrids.*

Correlation between	Calculated r		
	Inbred lines	Single crosses	Double crosses
Days from planting to silking, and percentage of plants with bleached husks on Sept. 5	−0.514	−0.676	−0.415
Days from planting to silking, and percentage of dry matter in grain, Sept. 14	−0.603	−0.814	−0.735
Days from planting to silking, and percentage of dry matter in grain, Oct. 12	−0.325	−0.539	−0.182
Percentage of plants with bleached husks on Sept. 5, and percentage of dry matter in grain on Sept. 14	0.692	0.648	0.514
Percentage of plants with bleached husks on Sept. 5, and percentage of dry matter in grain on Oct. 12	0.484	0.511	0.353
Percentage of dry matter in grain on Sept. 14, and percentage of dry matter in grain on Oct. 12	0.560	0.598	0.478
D. F	66	123	23
Significant r (1% level)	0.317	0.230	0.505

The correlations computed between silking date and percentage of dry matter in the grain on September 14 were negative and highly significant in all three groups. The correlations of −0.814 in the single crosses and −0.735 in the double crosses indicate a closer relationship between these two measures than between any of the others. In the inbred lines the correlation was slightly greater between the percentage of plants with bleached husks on September 5 and the percentage of dry matter on September 14.

The correlation of −0.182 between silking date and percentage of dry matter at harvest on October 12 was not significant in the double crosses even on a basis of a 5% level. This is of special interest because both criteria are used extensively in measuring the maturity of commercial hybrid corn. If there is in general as little relationship between these two characters as appears from these studies with double crosses, the number of days from planting to 50% silking and the percentage of dry matter at harvest should not be regarded as equal measures of maturity. However, it is probable that in years when the corn is not so dry as in 1939, the relationship might be greater. The dry matter content of the double crosses on October 12 was rather uniform, ranging only from 83 to 88%. The extended dry

weather of 1939 doubtless reduced the moisture content of many of the later-silking strains of corn below that usually carried by these strains in more normal seasons.

The percentage of plants with bleached husks at the approach of maturity seems to be an indication of the percentage of dry matter in the grain at that time as highly significant correlations were obtained among both inbred lines and single crosses. The correlation for the double crosses was about equal to the 1% level of significance for 23 degrees of freedom. These data were obtained under conditions where the ear-shanks were relatively free from Diplodia and other pathogenic infections. However, it is believed that this relationship would not be materially affected under conditions where the ear-shanks are diseased, since loss of moisture in all ear parts seems to be associated with diseased shanks.

The percentage of plants with bleached husks on September 5 showed less correlation with the percentage of dry matter on October 12 than on September 14, although significant coefficients were obtained in the inbred lines and the single crosses. The correlation of 0.353 for the double crosses is below the 5% level of significance.

The coefficient of correlation between the percentage of dry matter on September 14 and on October 12, was large enough to be considered significant for the inbred lines and single crosses, and greater than the 5% level of significance for the double crosses.

DISCUSSION

Dry matter content of the grain at a proper stage of development is probably the best measure of relative maturity. It is self-evident that a "proper stage" is one at which a wide range in dry matter content is found between the earliest and latest maturing strains being compared. This stage will vary, as to date of occurrence, with seasonal conditions. For example, in the present study in 1939, October 12 was not a suitable time, because all strains had reached fairly uniform dry matter content. On September 14 the range in dry matter content was fairly wide, and for this reason the stage of development on that date was a more suitable one for comparisons of relative maturity.

Having established a basis of comparison, the other methods tried may now be evaluated. Correlation coefficients indicate that both number of days from planting to silking and the percentage of plants with bleached husks are satisfactory indices of relative maturity, the former being slightly better than the latter *in the season under consideration*. Dry matter content on October 12 is a poor index of relative maturity for reasons previously given.

It is well to recognize that unusual environmental conditions may alter the value of the different measures of maturity. For instance extreme drouth or hot winds while the corn is in the milk stage would encourage premature drying and as a result all strains would reach a rather uniform moisture content at approximately the same time even though they were not in a true sense mature.

SUMMARY

In a study of indices of relative maturity of corn grown in 1939, coefficients of correlation were calculated among the number of days from planting to 50% silking, percentage of plants with bleached husks on September 5, and percentage of dry matter in the grain on September 14 and at harvest on October 12.

A total of 218 entries were used in this study, including 68 inbred lines, 125 single crosses, and 25 double crosses.

In general the correlations were highest among the single crosses and lowest among the double crosses.

The most significant correlations were between silking date and the percentage of dry matter on September 14, while the least significant was between silking date and dry matter at harvest time (October 12) in the double crosses. This indicates that the percentage of dry matter at harvest time may not be closely associated with the number of days to silking in double crosses that are as thoroughly dried at harvest as they were following the dry weather of 1939.

The significance of these various indices of relative maturity is discussed.

A QUALITATIVE COLOR TEST FOR THE MONTMORILLONITE TYPE OF CLAY MINERALS[1]

STERLING B. HENDRICKS AND LYLE T. ALEXANDER[2]

MONTMORILLONITE is one of the several clay minerals often found in the clay fraction of soils and its identification is important in problems of soil genesis. During the study of some organic salts of montmorillonite it was observed that characteristic color reactions were given by certain aromatic diamines. Further investigation has shown that these color reactions can be used as qualitative tests for montmorillonite in the presence of other clay minerals and constituents of soils, but in the absence of organic matter.

THEORY OF REACTION

A typical reaction is that of benzidine or its hydrochloride which give deep blue colors when added in dilute solution to suspensions of montmorillonite such as the commercially available volclay or Mississippi materials. The color is apparently due to fortuitous oxidation of a very small amount of the diamine to the semiquinone form which is known to be an "odd electron" compound. Other diamines that can be oxidized to semiquinone forms give the colors of these forms when added to most montmorillonite suspensions.

Discussion of the nature of these colored compounds is closely connected with color theories for triphenylmethane dyes and Wurster's salts.[3] It was first thought that the Wurster salts were molecular compounds between the oxidized and reduced forms of the molecule[4] to which the name meriquinoid was given by Willstätter. The extensive work of Michaelis and his collaborators, however, has shown that the colored forms are monomolecular[5] in most cases and are typical odd electron compounds. Thus Wurster's red salt which is obtained by oxidation of *asymm*-dimethyl-p-phenylene-diamine is shown to be a resonance hybrid of two odd electron forms (Fig. 1).

All diamines tested that were known to give semiquinone forms on oxidation gave the corresponding colors when added to montmorillonite suspensions. These were:

o-phenylene diamine	red
p-phenylene diamine	blue
benzidine	blue

[1]Contribution from the Fertilizer Research Division, Bureau of Agricultural Chemistry and Engineering, and the Soil Chemistry and Physics Division, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication April 5, 1940.

[2]Senior Chemist and Chemist, respectively.

[3]Note "Sidgwick's Organic Chemistry of Nitrogen," T. W. J. Taylor and W. Baker, p. 82 ff., London, 1937 for a discussion of the structure of these dyes.

[4]KEHRMANN, F. On some colored and colorless diimines. Berichte, 38:3777–3778. 1905.

[5]MICHAELIS, L. Semiquinones, the intermediate steps of reversible organic oxidation-reduction. Chem. Rev., 16:243–286. 1935. PAULING, L. Nature of the Chemical Bond. 1939. (Pages 256–263.)

assym-dimethyl-p-phenylene diamine........red
tetraethylparaphenylenediamine............blue
2–7 diamino fluorene... ....blue
2–5 diamino fluorene. ... .blue

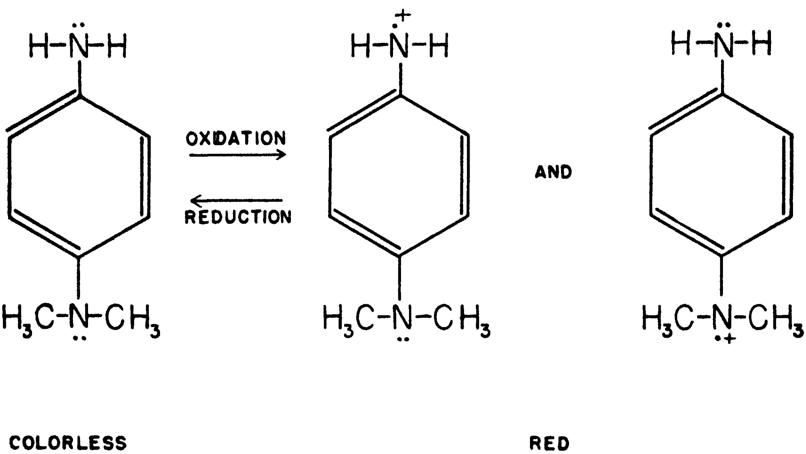

FIG. 1.—Forms of Wurster salts.

Aromatic diamines such as m-phenylene diamine that cannot be oxidized to semiquinones did not give color reactions with montmorillonite and this is also true of a large number of monoamines.

The colored form was strongly attached to the montmorillonite, presumably replacing an exchangeable ion. It does not noticeably fade over a period of 6 months after the clay has dried and is not unstable in solution. Attempts to exclude oxygen, by prolonged boiling in an atmosphere of nitrogen, so thoroughly as to prevent oxidation have not been successful. It is probable that the oxidation is due to the presence of ferric iron or an equivalent oxidizing agent in an insoluble form together with or a part of the montmorillonite. Very pure samples of montmorillonite such as the material from the Island of Ponza and some specimens from Otay, California, gave only very faint blue colors with benzidine due apparently to the absence of iron compounds. Freshly prepared $Fe(OH)_3$ and the iron compounds present in soils did not give semiquinones in the absence of montmorillonite. Presence of manganese dioxide interferes with the test by action as an oxidizing agent. Ferrous iron or other reducing agents in solution prevent development of the semiquinones in the presence of montmorillonite.

The following experiment shows that the color development depends upon formation of a salt between the benzidine and montmorillonite. About 2 millimols of codeine or brucine is added to a suspension of a gram of montmorillonite such as commercial volclay (base exchange capacity 0.9 M. E. per gram). Benzidine added to the resulting system gives only a faint blue color, while a deep blue quickly develops in the absence of the alkaloid. The explanation is that the

large and more basic alkaloid molecule is far more firmly held as a cation than is benzidine and thus prevents formation of the latter salt. This experiment also demonstrates that the presence of an oxidizing agent alone in the clay is inadequate for the test.

RESULTS WITH MINERALS AND SOILS

An extensive series of tests were carried out with ortho- and paraphenylenediamines on several samples each of various pure and impure clay minerals. No color reactions were obtained with halloysite, hydrated halloysite, kaolinite, kaolinite ground for 12 days, and glauconite. Negative results also were obtained with silica gel, glaucosil (silica obtained by acid leaching of greensand), goethite, hematite, and sericite. Seven of eight bentonite samples supplied by Dr. R. E. Grim of the Illinois Geological Survey gave various shades of pink, red, and brown with o-phenylenediamine and dark to very dark blue with p-phenylenediamine. The eighth sample, from Hot Springs Co., Arkansas, which was marked as questionable material did not give a color reaction with either diamine. This also was the case with two samples of magnesium bentonite from Hector, California, one of which was the described material and the other a sample of commercial "eyrite". Magnesium bentonite is known to differ from the usual montmorillonite in other properties and to be very free of iron-bearing impurities. Positive results were obtained with other montmorillonite and nontronite specimens.

Clay fractions of several soils for which thorough mineralogical analyses had been made were tested with benzidine.[6] Positive results were obtained only for Miami C10343, Carrington C10086, Barnes C10307, and a desert soil C3420. Montmorillonite had been previously identified only in the clay fraction of the Carrington and Barnes soils. The clay fraction of the Miami and desert soils, however, contained large amounts of hydrous mica which readily grades into a mixed layer mineral with montmorillonite as a component. For the last few months the test has been used together with the differential thermal analysis method on a number of clay fractions from soils and has been found to be completely trustworthy in the absence of organic matter.

Recent experiments in the field have shown that organic matter frequently gives the test. Unless it is removed the test is limited to horizons containing only small amounts of organic matter. Removal of this matter is a simple procedure in the laboratory by means of oxidation with hydrogen peroxide but may cause trouble in the field and thus limit the applicability of the test. Organic matter from different sources varied greatly in development of color with benzidine solutions.

Benzidine hydrochloride is recommended for use in applying the test. The solid can readily be obtained and is stable when kept in a brown bottle. Solutions slowly oxidize but can be used after standing

[6] ALEXANDER, L. T., HENDRICKS, S. B., and NELSON, R. A. Minerals present in soil colloids: II. Estimation in some representative soils. Soil Sci., 48:273–279. 1939.

for 2 months in brown glass. The blue color is not obscured by iron-bearing minerals of most soils. It is not necessary to separate the clay fraction but some advantage is gained by a single decantation from coarse material. Small amounts of montmorillonite in red or brown soils give green and greenish-blue colors as would be expected. The hydrogen-ion concentration is not critical, but in moderate acid concentrations green colors are obtained.

HOW TO MAKE THE TEST

Organic matter, if present in quantities sufficient to interfere, should be decomposed by treatment with moderately strong hydrogen peroxide and this removed by evaporation to dryness at less than 100° C. Benzidine or its hydrochloride either as solid or in water solution is added. A few milligrams of the solid or a few cc of the saturated solution are added when added to a few grams of soil. The blue or greenish-blue color characteristic of the montmorillonite type of clay mineral may develop rather slowly at room temperature. Warming will hasten the reaction, but it is best to allow the mixture to stand for several hours in any case.

The test is now being tried by the U. S. Soil Survey, the U. S. Geological Survey, the U. S. Bureau of Mines, and various university laboratories. It is a pleasure to acknowledge the cooperation of these organizations. Dr. L. Michaelis of the Rockefeller Institute for Medical Research kindly supplied samples of several diamines.

CONCLUSIONS

Organic diamines that can be oxidized to semiquinone forms undergo catalytic oxidation in the presence of the clay mineral montmorillonite. Since the oxidized forms are highly colored their production can be used as a simple qualitative test for montmorillonite in soils. Kaolinitic clay minerals and other inorganic constituents of soils give negative results. Organic matter, however, frequently gives the test which limits its simple application in the field.

DORMANCY IN FATUOID AND NORMAL OAT KERNELS[1]

F. A. Coffman and T. R. Stanton[2]

THE widespread occurrence of fatuoid or false wild oats (Fig. 1) is generally recognized by plant scientists familiar with oats. The nature of their origin has been the object of controversy for many years and the problem has been attacked from the genetic, the cytologic, and the physiologic standpoints. Two theories have been advanced to explain their occurrence. One theory assumes that fatuoids result from mutation and the other that they result from natural crossing, probably with wild oats (*Avena fatua*). Each theory has many adherents and the literature on genetic and cytologic studies on this subject is so extensive that no attempt is made to review it at this time. Stanton, Coffman, and Wiebe (8)[3] and more recently Coffman and Taylor (1) have presented rather complete reviews of the literature on these subjects.

Physiologic studies of these aberrant oats have been limited. The well-known observation that freshly harvested seed of *Avena fatua*, the common wild oat, frequently does not germinate promptly is supported by ample data. It is largely this character of dormancy that tends to make the wild oat a noxious weed. However, very few data on the dormancy of fatuoids or of cultivated oats are available. Fischer (5) and Criddle (3) report that fatuoids germinated in the autumn while wild oats normally do not.

Garber and Quisenberry (6) studied delayed germination in seed of wild and false wild oats and of hybrids between wild and cultivated oats. They concluded that seeds of *Avena fatua* and some of its hybrids possessed the property of delayed germination but found no evidence of delayed germination in seed from homozygous false wild oats, heterozygous false wild, or from *A. sativa* varieties. Their physiologic studies were limited to seed of only three varieties of *A. sativa*, namely, Victory, Garton No. 748, and Aurora.

Deming and Robertson (4) observed dormancy in Kanota oats (*Avena byzantina*) but little, if any, in the two varieties of *A. sativa*, Nebraska 21, and Colorado No. 37, which they tested.

Johnson (7) reported dormancy studies of *Avena fatua* which indicated "Great variations . . . in the after-ripening periods of a number of *A. fatua* selections".

Coffman and Stanton (2) tested for dormancy the freshly harvested seed of 25 distinct varietal types belonging to six species and subspecies. They observed indications of dormancy in seed of varieties of *Avena byzantina*, *A. fatua*, and *A. sterilis*. A single variety of *A. nuda* germinated promptly. Varieties of *A. sativa* and *A. sativa orientalis* differed, some being prompt and others more or less delayed in germination.

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[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication April 8, 1940.

[2]Agronomist and Senior Agronomist, respectively.

[3]Numbers in parenthesis refer to "Literature Cited," p. 466.

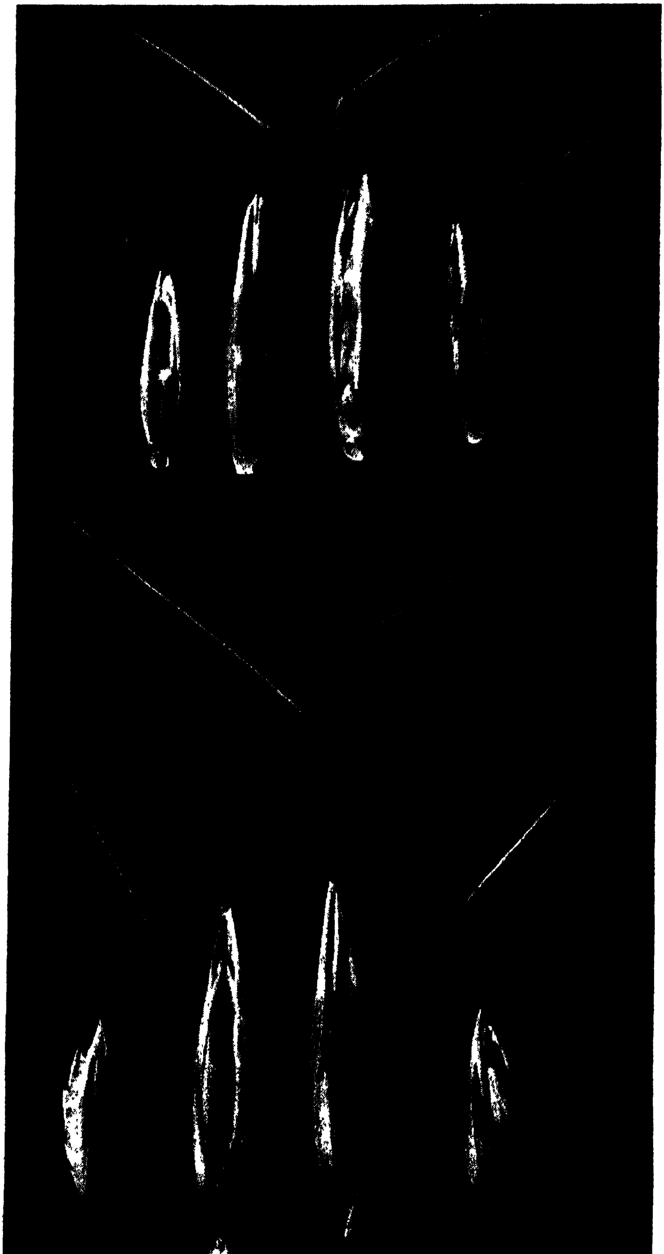

FIG. 1.—*Upper*, fatuoids from the *Avena sativa* variety Victory; *lower*, fatuoids from the *A. byzantina* variety Fulghum.

In view of the fact that fatuoids occur in so many oat varieties and that oat varieties differ as to dormancy or after-ripening of their seed, it is of interest from the standpoint of the origin of fatuoids to determine the relationship, if any, between the promptness of germination of freshly harvested fatuoids and that of seed of the respective variety in which the fatuoids occur. This study was suggested by J. H. Martin of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

MATERIALS AND METHODS

Two separate experiments were conducted to determine dormancy in fatuoid and normal oats. In one the seed was obtained from plants grown in the greenhouse and germinations were made in a standard germinator in the laboratory at approximately room temperature, or about 65° to 70° F. The seed used in this test was collected in 1937 from several varieties in different parts of the United States. In each case, normal or typical panicles from neighboring plants were collected for comparison. Seed from aberrant and normal plants of each variety was sown in pots in the greenhouse at Washington, D. C. Usual greenhouse technic was followed in growing the plants, and when mature the plants were harvested, the panicles threshed, and the seed put into the germinator immediately.

In the second experiment the fatuoid and normal oats were collected from plots and nursery rows on the Aberdeen Substation, Aberdeen, Idaho, in 1938. The fatuoid plants, together with adjacent normal plants, were gathered when the oats were mature. The seed was threshed immediately and placed between moistened blotters which were rolled in cloth bags. These were placed in a basement laboratory at a comparatively uniform temperature of about 65° to 70° F and were kept moist. In all cases, seed from a single plant constituted a sample, which was necessary in order to detect any heterozygosity among different fatuoid individuals from the same variety. Frequently this necessitated testing samples of comparatively few seeds. The samples usually, although not always, contained 25 seeds. With few exceptions, germination counts were made at 3-day intervals. In all tests any seed showing a protruding coleoptile was considered as having germinated.

EXPERIMENTAL DATA

Data are presented from 29 homozygous and 10 heterozygous fatuoids as compared with those from 33 plants of the normal type of the parent varieties. Tests were made on fatuoids from 16 different varieties, 4 classed morphologically as belonging to *Avena byzantina* and 12 as belonging to *A. sativa*. In the *A. sativa* group fatuoids from early, midseason, and winter oat varieties of *A. sativa* were tested, but in *A. byzantina* the varieties represented were all early.

The germination of seeds from 21 homozygous and 4 heterozygous fatuoids was compared with that from normal plants in the greenhouse at Washington, D. C., and 9 homozygous and 5 heterozygous fatuoids were compared with normal plants of the respective varieties in the experiments at Aberdeen, Idaho.

TESTS ON SEED GROWN IN GREENHOUSE

The data in Table 1, except for one sample, show very slow or delayed germination of freshly harvested seed from both fatuoid and

TABLE 1.—*Germination of freshly harvested normal oats and fatuoid oats collected from the same varietal plots in seed grown in the greenhouse.*

Variety	C. I. No.	Collection No.	% normal germination after 6 days	13 days	18 days	27 days	34 days	% fatuoid germination after 6 days	13 days	18 days	27 days	34 days
			***Avena byzantina*, early**									
Frazier	2381	1	0	—	20	30	—	25	—	75†	—	—
Kanota.....	839	1	30	—	40	—	—	50	—	—	—	—
Kanota.....	839	1*	—	—	—	—	—	90	95	—	—	—
			***Avena sativa*, early**									
Richland....	787	1	32	—	40	72	84	80	100	—	—	—
Iogold.....	2329	1	0	—	27	62	100	50	—	90	100	—
Iogold	2329	2	80	—	—	—	96	28	44	80	84	—
Iogold......	2329	3	75	80	85	—	100	12	37	—	49	61
Boone.....	3305	1	100	—	—	—	—	100	—	—	—	—
Boone.....	3305	2	72	92‡	—	—	—	75	87†	—	—	—
Boone.. .	3305	3	87	100	—	—	—	75	100	—	—	—
Boone......	3305	3*	—	—	—	—	—	90†	—	—	—	—
Early Joanette	1092	1	0	—	—	—	—	—	—	—	—	—
Early Joanette	1092	1*	—	—	—	—	—	5	—	—	—	—
Markton × Iogold.....	3352	1	96	100	—	—	—	95	100	—	—	—
Bond × Iogold	——	1	100	—	—	—	—	90†	—	—	—	—
			***Avena sativa*, midseason**									
Abundance .	755	1	100	—	—	—	—	100	—	—	—	—
Abundance.	755	1*	—	—	—	—	—	100	—	—	—	—
Bannock.....	2592	1	100	—	—	—	—	100	—	—	—	—
Bannock....	2592	2	100	—	—	—	—	80	100	—	—	—
Bannock.....	2592	3	100	—	—	—	—	96	100	—	—	—
Bannock... .	2592	4	100	—	—	—	—	98†	—	—	—	—
Bannock...	2592	5	100	—	—	—	—	94	—	98†	—	—
Bannock....	2592	6	100	—	—	—	—	100	—	—	—	—
Bannock....	2592	7	100	—	—	—	—	—	—	—	—	—
Bannock....	2592	7*	—	—	—	—	—	70	80	95†	—	—
Swedish Select	134	1	100	—	—	—	—	100	—	—	—	—
Swedish Select	134	2	100	—	—	—	—	70	100	—	—	—
			***Avena sativa*, winter oat**									
Lee	2042	1	40	100	—	—	—	80‡	—	—	—	—

*Intermediate fatuoid.
†One seed rotted.
‡Two seeds rotted.

normal plants in the two varieties of red oats, Kanota and Frazier. These results are not wholly conclusive because the number of fatuoid seeds from the greenhouse cultures of both varieties was small. A test of seed from fatuoids and normal plants of Coker 33–15, a third red oat variety, was started but unavoidable conditions prevented its being completed. However, after the seed had been in the germinator for 13 days the germination for the different collections of that variety varied from 0 to 37% for the fatuoids, 0 to 28% for the intermediate fatuoid forms, and from 0 to 20% for the normals. These results indicate that there is no difference in the time of germination of fatuoid and normal seeds of Coker 33–15. This variety undoubtedly germinates slowly.

It will be noted that, in general, rather slow germination was shown by both Richland and Iogold. Germination of all the seeds had not occurred even at the end of the thirty-fourth day after being put in the germinator. These varieties showed some difference in germination between the fatuoid and normal oats. The slow germination of both Richland and Iogold conforms with results obtained by Coffman and Stanton (2).

Except for Early Joanette, all the remaining varieties of common oats showed very prompt germination. This was true of fatúoid, intermediate, and normal oats. This rapid and complete germination of all seeds of varieties such as Swedish Select, Bannock, Abundance, Boone, and the homozygous selections from the two hybrid combinations indicates rather definitely that fatuoids conform in time of germination with that of the cultivated or normal populations in which they occur. The very prompt germination of these varieties may have been favored by allowing them to remain in the greenhouse a little longer after maturity than in the case of the Richland and Iogold varieties. However, even when ample allowance is made for some after-ripening, there is no doubt that varieties such as Bannock and Swedish Select germinate promptly.

Lee was classed by Coffman and Stanton (2) as being slow in germination, but in the present test Lee germinated rather promptly. Early Joanette showed delayed germination, thus agreeing with the results on this variety published by these investigators.

STUDIES OF FIELD-GROWN SEED

In the tests (Table 2) conducted at Aberdeen, Idaho, there was a tendency for seed of all varieties to be somewhat slower to start germinating than was found by Coffman and Stanton (2) in their tests of dormancy conducted on greenhouse-produced seed. The reason is not known. The data obtained indicate, however, that some variation may occur in the promptness of germination of seed from different plants of the same variety. Victory, for example, was classed by Coffman and Stanton (2) as "prompt" in germination, but a difference of several days occurred in the initial germination recorded on seed from different plants of that variety in tests conducted on field-grown seed at Aberdeen, Idaho.

Freshly harvested seed from both the fatuoid and the normal plants of the Fulghum variety (*Avena byzantina*) was decidedly slow

TABLE 2.—*Germination of freshly harvested seed of normal oat plants and fatuoid plants collected from the same plots at Aberdeen, Idaho, in 1938.*

Variety	C. I. No.	Collection No.	% normal germination after									% fatuoid germination after								
			4 days	7 days	10 days	14 days	18 days	22 days	27 days	30 days	40 days	4 days	7 days	10 days	14 days	18 days	22 days	27 days	30 days	40 days
			Avena byzantina, early																	
Fulghum	708*	1	0	—	—	—	—	—	—	—	90	—	—	—	—	—	—	—	—	—
Fulghum	708	1†	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	10
Fulghum	708	2	0	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—
Fulghum	708	2‡	—	—	—	—	—	—	—	—	—	0	10	—	—	—	30	—	—	60
Fulghum	708	3	0	—	—	—	—	—	—	—	40	0	—	—	—	—	—	—	—	40
Fulghum	708	4	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	10
Fulghum	708	5	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	25
Fulghum	708	5	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	30
			Avena sativa, midseason																	
Abundance	755	1	0	—	36	70	100	—	—	—	—	—	—	—	—	—	—	—	—	—
Abundance	755	1†	—	—	—	—	—	—	—	—	—	0	—	15	—	75	85	—	—	—
Abundance	755	2	0	10	15	55	65	90	—	—	—	0	10	35	75	—	90	95	100	—
Abundance	755	3	0	—	10	85	100	—	—	—	—	0	4	16	60	84	92	—	—	—
Andrew A	2239	1	0	—	15	60	72	80	84	92	100	0	60	75	100	—	—	—	—	—
Victory	2020	1	0	5	85	95	—	—	—	—	—	0	—	45	80	95	—	—	—	—
Victory	2020	2	0	—	45	75	85	95	—	—	—	—	—	—	—	—	—	—	—	—
Victory	2020	2†	—	—	—	—	—	—	—	—	—	0	10	80	100	—	—	—	—	—
Victory	2020	3	0	20	73	94	100	—	—	—	—	—	—	—	—	—	—	—	—	—
Victory	2020	3†	—	—	—	—	—	—	—	—	—	0	10	60	80	—	90	—	—	—

*All samples of C. I. 708 were taken from one plot.
†Intermediate fatuoid.
‡Black-kerneled intermediate fatuoid.

in germinating. Only one sample showed any germination after 30 days. This sample from an intermediate fatuoid plant had germinated 10% by the seventh day following harvest and 30% 22 days after harvest. By the end of the test (40 days) it had germinated 60%. One sample of Fulghum germinated reasonably well (90%) during the course of the test, while another showed no germination after 40 days in the germinator. Both fatuoid and normal seeds of the Fulghum variety were decidedly delayed in germination.

In the tests of varieties of *Avena sativa* three comparisons were made between seed of fatuoid and normal plants of the Abundance variety. One fatuoid and one cultivated sample did not start germinating until the tenth day after harvest. Germination in all others had started by the seventh day, and all samples, both fatuoid and normal, germinated more than 90% by 27 days following harvest. Consequently, no dormancy was evident in either the normal or fatuoid seed.

One fatuoid from the *Avena sativa* variety Andrew A was compared with normal seed of that variety. The fatuoid seed germinated 60% 7 days following harvest and 100% by the fourteenth day, whereas the cultivated or normal seed had germinated 15% by the tenth day and 100% of the kernels had germinated 40 days following harvest. Here normal seed showed a greater tendency toward dormancy than the fatuoid seed.

Three pairs of comparisons were made with normal and fatuoid oats from the *Avena sativa* variety Victory. This variety was classed as prompt in germination by Coffman and Stanton (2). Two samples each of the normal and fatuoid seeds had started germinating by the seventh day and all three were partially germinated by the tenth day. All samples from the Victory variety, both cultivated and fatuoid, had germinated 75 to 100% by the fourteenth day and all finally germinated 90 to 100%. Consequently, no evidence of dormancy was observed in seed of either normal or fatuoid from Victory.

SUMMARY

Freshly harvested seed of fatuoid and normal oat plants from 12 varieties of *Avena sativa* and 4 varieties of *A. byzantina* was tested to determine the relationship in dormancy between fatuoid and normal plants of the same variety. Comparisons were made of seed grown both in the field and greenhouse.

In the tests made when dormancy occurred in the normal plants of a variety of oats it also occurred in fatuoids from that variety, and when germination was prompt, the seed of the fatuoid of either the homozygous or the heterozygous intermediate plant forms also germinated promptly. This seems to furnish evidence for the belief that fatuoids result from mutations rather than from natural crosses with *Avena fatua* inasmuch as the seed of the latter usually has a decided tendency toward dormancy.

The experiments also indicated that characters associated with fatuoids, such as the "suckermouth" form of base, the presence of basal hairs on the callus, etc., were unrelated to dormancy in oats.

Coffman and Stanton (2) observed previously that these kernel characters were often found in oat varieties having a tendency to dormancy but stated that their association with dormancy might be merely accidental.

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THE USE OF CLASS WORDS IN AGRONOMY[1]

WILBERT W. WEIR[2]

SCIENTIFIC agricultural literature reveals much confusion in the use of class words, that is, words that stand for classes of things. There seems to be much confusion in the use of the terms "species," "genus," "soil type," and "soil series." Apparently the fact that all class names are general words, and hence abstract,[3] is too often overlooked. Moreover, it is common to see a class word used as though it named something that has materiality. Careless use of class words and their confusion with collective nouns, with nouns that have the same form in the plural as in the singular, and with mass words may make difficult a clear understanding of the meaning intended.

The terms "large species" and "small species" appear often. What is meant? Small and large genera embrace few and many species (classes). Small and large *species*, on the other hand, cannot imply species that embrace few and many classes, respectively. When plants are considered, small species would mean plants that naturally make short height growth, as compared with plants of other species of the same genus.

It is commonly stated that *the soil* is a specific object in nature, and that it may be divided into many groups, soil series being the most important. Such a statement implies that, as a material object, "the soil" has individual character in the sense that the earth has, for example. If this were so, would soil classification consist in dividing "the soil" as unity into various parts, and then grouping these parts into series? Logically, how can this be? Soil classification assumes the existence of individual soils as earthy bodies, and these earthy bodies are classed, in general, as *soil*. In natural classification, soils are first grouped according to their similarity into type classes; and type classes, in turn, are grouped according to identical characteristics into larger classes called series; and series, into family groups, and so on.

A keen observer of natural phenomena wrote that he "saw *Crotalus atrox* at an elevation of 8,000 feet." Here a Latin or scientific class word, which is abstract, has been used as though it named something that had individual character. Specifically, rattlesnakes of the species *Crotalus atrox* were seen. In this instance, a clear statement of fact that would be appreciated by laymen and others who do not know snake classification would be, "Western diamond rattlesnakes of the species *Crotalus atrox* were seen at an elevation of 8,000 feet."

Recently there appeared an article on "germination of *Quercus alba* and *Juglans nigra*." The meaning intended was the germination of white-oak acorns and nuts of black-walnut trees.

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[1]Contribution from the Southwestern Forest and Range Experiment Station, U. S. Forest Service, Tucson, Ariz. Received for publication April 9, 1940.

[2]Forest Ecologist.

[3]See under "Abstract, 3, b" and "Abstraction, 3" in recent editions of Webster's New International Dictionary.

SPECIFIC VS. GENERAL WORDS

According to Weseen,[4] authorities on rhetoric warn against the excessive use of general words, that is, words that stand for whole classes of objects or actions. It is generally accepted that thought can best be expressed by specific words, because they are more accurate, clearer, and more interesting. Specific words tell something definite. No doubt most students of rhetoric have seen sentence comparisons like the following: (General words.) "The man went to see the group." (Specific words.) "The hunter hobbled to gaze at the dancers."[5] Compare also the following two sentences: Soil reaction affects soil organisms. Soil acidity may retard the activity of azotobacters.

In the sentence, "In some places poisonous *Drymaria* is getting more abundant," *Drymaria* is the name of a genus of plants that occur on some southwestern ranges. Those of the species considered are poisonous. Poisonous *Drymaria* certainly does not name a crop. If it did, it would be used as a collective noun, as are the words "corn" and "cotton." Nor is it a plural singular, that is, a noun that has the same form in the plural as in the singular, like the words "deer" and "grouse." In the above sentence, the phrase "in some places" calls for a specific word. The thought also calls for specific words, because the plants included in the genus "*Drymaria*" are not all confined to the few places where they are increasing in number. They occur in other places also, but in the other places they may not be on the increase. A clear, logical statement of the fact would be, "In some places poisonous drymarias are increasing in number," just as one would say that in some soils rhizobia are increasing in number, or that in some soils actinomycetes are less numerous than protozoans.

CLASS WORDS DESIGNATE KINDS

Sometimes it is convenient to express thought in the form of lists. In lists, likewise in classifications, kinds are briefly stated. Hence, lists that designate kinds should be built with class words, for *class* means kind.

Ordinarily, in scientific agricultural writings, common class names are given preference in designating kinds. But when a common class name for the plants of a genus or of some higher class is lacking, a common name may be derived from the Latin or Greek class name. The name thus derived is not italicized.[6] In biology most such derived names are not capitalized. Some such names, particularly in soil science, retain the capital letters. Series in soil classification, for example, are given geographic names, and hence they retain the capital letters. Webster's New International Dictionary (recent editions) has become a valuable aid in the use of scientific class names and of English names (of plants or animals of the class) derived therefrom. To illustrate:

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[4]Crowell's Dictionary of English Grammar, by Weseen. New York. 1928.
[5]*Idem.*
[6]The scientific names of genera, subgenera, species, and sub-species (varieties) are italicized, whereas the names of classes of higher rank are not.

Scientific class name (Abstract)	Individual thing (Concrete)	Individuals plural form (Concrete)
Poinsettia	a poinsettia	poinsettias
Rhizobium	a rhizobium	rhizobia
Azotobacter	an azotobacter	azotobacters
Actinomyces	an actinomycete	actinomycetes
Norfolk loam	a Norfolk loam	Norfolk loams
Protozoa	a protozoan	protozoans
Leguminosae	a legume	legumes
Chernozem (soils)	a chernozem	chernozems

Ordinarily, in biology, a simple rule to follow in capitalization of scientific class names and the names of the natural objects concerned is that the name of a genus or of a higher class is capitalized when used as a scientific class name, but is written with a lower-case letter when used as a common English class name and also when used to name a plant, an animal, plants, or animals of the genus or of the higher class.[7]

A list may be built entirely of scientific class words (purely technical list), or it may include names of various classes that belong to the different categories of the classification considered. Ordinarily, specific kinds of plants are indicated by the English, or common, class names, supplemented (in parentheses) with scientific class names, usually of species or genera, as white oaks (*Quercus alba*). With respect to the common names, more than one kind of any particular class may be indicated by the plural form of the common, or English, class word. Whether more than one species are considered in each case may be indicated (in parentheses) in either of the following three ways: (1) by the names of the species considered, (2) by the abbreviation "spp." after the name of a genus, or (3) simply by the name of the genus or of some higher class without the abbreviation "spp.," as shown in the following example:

The plants studied were of the following kinds:
gramas (*Bouteloua eriopoda*, *B. trifida*) [Two species of grasses.]
pines (*Pinus strobus*, *P. resinosa*) [Two species.]
wheat (*Triticum vulgare*) [One species.]
beans (*Phaseolus vulgaris*) [One species.]
cacti (*Opuntia* spp.) [Several species.]
tobaccos (*Nicotiana*) [All species.]
rhodendrons (*Rhododendron*) [All species.]

CLASS WORDS IN DISCOURSES

In discourses, as well as in sentences that may be necessary to insert in lists, clear expression of thought usually calls for the names of the objects considered rather than for names of their classes. In discourses, class words are probably of most value in enabling one to refer to natural objects by kinds. Such use can help one over certain

[7]Rule suggested, in correspondence, by Dr. J. P. Bethel, of G. &. C. Merriam Company, publishers of Webster's New International Dictionary.

rough places, especially when it may be necessary to include some scientific class names when common names are lacking. Moreover, in a series of names, it is conceded as good form by authorities on rhetoric to have specific or "thing" names keep company with specific names, and to have class words keep company with class words. To illustrate: (Not an approved form.) "We found yuccas, burroweed, and some paloverde." In this sentence the word "yuccas" refers to specific plants, whereas "burroweed" and "paloverde" are common names of classes of plants. Approved usage could be either "yuccas, borroweeds, and a few paloverdes," or if in each case the plants are of a single species, "plants of such kinds as yucca, burroweed, and paloverde."

Two examples of approved usage follow: (1) There were plants of such kinds as yuccas (*Yucca* spp.) and mesquite (*Prosopis juliflora*). (2) In that area are pines (*Pinus ponderosa*), spruces (*Picea engelmannii* and *P. parryana*), and a few scattered junipers (*Juniperus monosperma*); whereas in an adjoining area there are a few ponderosa pines and also grasses and shrubs of such kinds as fescues (*Festuca* spp.), needlegrasses (*Stipa* spp.), junegrass (*Koeleria cristata*), muhly grasses (*Muhlenbergia*), Apache-plume (*Fallugia paradoxa*), and *Oryzopsis*.

It is of interest to note that lexicographers and authorities on rhetoric do not regard words like "pine," "oak," and "coffee," as collective nouns nor as plural singulars. However, such terms may be used as mass words[8] when reference is made to something that may be considered as uncountable units, as, "He deals in pine," meaning pine building materials. However, the word "pine" may be used in the plural when reference is made to pine seedlings or trees (as several pines) and to kinds (as two kinds of pines).

In purely technical papers, scientific class names are commonly used for the exact designation of organisms, plants, and animals when they have no common names, as ". . . *Thielavia basicola*, capable of attacking roots . . ." Here reference is made to parasitic organisms of the class *Thielavia basicola*.

GENERIC, OR GENERALIZED, USE OF CLASS WORDS

By use of the generic singular, or generalized use of a class word, is meant the use of a class word in a sense to include all the individuals of the class considered. A few examples follow: In the sentence, "The pine is a conifer," "pine" is used in the general sense to mean that all pines are cone bearing.

In the expression, "The protection function of the forest . . .," the word "forest" is used in the general sense; the meaning is that every forest in the world gives protection to the ground surface. But in the following sentence the term "forest" cannot be used in a generalized sense, because all forests are not implied, only those of many populous regions: "Robbed of the protective influence of forests, many of the most populous regions have become inhospitable and even uninhabitable wastes."

[8]See Webster's New International Dictionary, recent editions, especially under "Plural, X, Mass words."

Another example is given, one that pertains to deteriorated vegetation: "Man, in his aggressive exploitation of nature, risks upsetting and destroying favorable conditions . . . ." Here the generic singular "man" is correctly used in a general sense, because the statement holds true wherever men have exploited lands.

Compare the following two sentences: "The American Indian hunted," and "The American Indian hunted in Massachusetts." The first statement is true, because all American Indians hunted. The second statement cannot be true, because it implies that all American Indians hunted in Massachusetts.

It is not necessary to precede a generalized word with *the*, as, "Primitive *man* selected food plants." A generic singular may be preceded by *a* or *an*, as, "This explains why *a* class *word* is abstract . . . ," which is the same as saying ". . . why all class words are abstract . . . ." Commonly, a generalized noun preceded by *a* or *an* may express the thought more clearly than when preceded by *the*, for example, "*A* class *word* is abstract; its meaning is applied the same to all members of the class."

The use of *the* with a generalized noun is quite different from its uses as a definite article when it (1) indicates pre-eminence (as, the Nile), (2) when it designates something previously mentioned or implied (as, of the flowers, the roses grew best), and (3) when it particularizes, as, the cat [not dog] caught the mouse [not rat].

A COMMON FALLACY IN THOUGHT

Fundamentally, the misuse of class words commonly involves a fallacy in thought, called, according to Bowne,[9] the fallacy of the universal. A clear understanding of this fallacy calls for a clear understanding of general concepts, which are also called universal concepts and general notions.

All class terms, such as *Crotalus atrox*, *Quercus rubra* (species), *Drymaria* (genus), *Norfolk loam* (soil-type class), *Norfolk* (soil series), red oak, oak, soil, and dog, are names of universal concepts. Being a general concept, *Quercus rubra* (red oak), for example, embraces all individuals in this class; and *oak* includes all oaks. The general concept "*Quercus rubra*," or "red oak," implies those characteristics that distinguish red oaks from oaks of other kinds. Likewise, *oak* as a universal concept implies all the characteristics that are common to all oaks. Accordingly, *Quercus rubra* (red oak) merely stands for all red oaks, and oak represents all oaks.

Inasmuch as the meaning of a class word implies those characteristics that are common to all members of the class, the general concept indicated by the class name is created by definition. In this manner we create all general concepts, as *Crotalus atrox*, *Norfolk loam*, oak, and soil. This explains why a class word is abstract; it has only meaning, and hence it can never be the name of something that has materiality or individual character.

The fallacy of the universal consists in mistaking a universal concept for something that has material existence. To illustrate: In the expression, "germination of *Quercus alba*," *Quercus alba* has been

[9]BOWNE, B. P. Theory of Thought and Knowledge. New York. 1897.

mistaken for something that has physical existence, when it is merely an abstract class name.

Compare the following two sentences: (Wrong) "In this region *Calliandra* is common on *White House gravelly sandy loam.*" (Correct) "In this region calliandras are common on White House gravelly sandy loams." In the first sentence, *Calliandra* is the name of a genus of shrubs, and *White House gravelly sandy loam* is the name of a class of similar loams (soils). Hence in each case a general concept has been mistaken for something that has materiality.

Again, in the sentence, "The soil is a specific object in nature," the error is obvious. The general notion *soil* has been mistaken for something that is of the earth itself.

Difficulties in thought that result from confusion in the use of names of material things and of classes are similar to those that led early philosophers to much dispute between realism and nominalism, that is, whether individual objects or general concepts had actual reality. But that problem of early dispute has long been settled. Modern thought recognizes a wide difference between specific and class words. For example, there is a wide logical difference between the term "red oaks" and the word "*Quercus rubra*" (red oak), and between dogs (things) and dog (general concept). The one term names material objects, whereas the other names a universal concept. Bowne has suggested a way to avoid fallacies of the universal: When writing, keep specific things and specific names in mind.

A question may be raised regarding the names of species. Are such names the names of individual objects? From the way the term "species" is commonly misused, one might be led to answer this question in the affirmative. Briefly, let us look into this matter.

According to standard dictionaries, the term "species" is given the following meanings:

In logic. A group or class of individuals that have common attributes and that are designated by a common name. For example, *white* may mean a group of white or near-white individuals; as in chess, white means one of two sets each of eight pieces and eight pawns, and may represent the player who has them.

In biology. A class, or group of plants or animals that possess in common one or more characteristics that distinguish them from other groups of similar plants or animals.

The term "genus" also means class or group. In scientific soil classification, type as class corresponds to species in biology; and series corresponds to genus. The terms "species," "genus," "soil type," and "soil series" are not collective nouns. A plant species may include innumerable individual plants in various parts of a country or of the world. Thus *Quercus rubra*, for example, is the name of a class of oaks. The individuals of this group are similar—that is, they have in common certain characteristics that distinguish them from all other oaks in the world. By the same token, *Chester loam*, for example, is the name of a group of similar soils. This class name (suggesting characteristics common to all individuals of this class) identifies all soils that have *Chester loam* features.

The conclusion with reference to species is that the name of a species, whether in logic or biology, is the name of a class of similar individuals. Thus the name of a species is abstract, and it does not name anything that has individual character or materiality.

As pertaining to the use of universal concepts, they need careful watching, especially those that are designated by common class names, such as *soil* and *mouse*. Moreover, one should guard against the excessive use of *the*. One is prone to generalize and say, for example, "the soil" and "the mouse." The use of collective nouns also needs careful watching, likewise those nouns that have singular forms but which are plural. Shall one say, for example, "A good stand of aspen" or "A good stand of aspens"? The meaning of the term "stand" determines. As used here, "stand" refers to the number and distribution of plants growing on a unit of area. Hence one should say, "A good stand of aspens." But one may say, "A good stand of cotton," and "A good stand of timber." (The terms "cotton" and "timber" are collective.) Many of the errors that result from the careless use of class terms and of words that accompany them may be regarded as thought monstrosities; for example, "The mouse is an abundant population in some places."

OTHER POINTS PERTAINING TO CLASS WORDS

Attention is called to two other problems that pertain to the use of class words, *viz.*, the adjective use of the names of genera and other classes, and the singular meaning of all class names.

One may wish to use the name of a genus or of a higher class to modify the term "plants," for example, when there is no common name. When this is done, it concerns the plants of that particular class, and should be written, for example, "many *Drymaria* plants." But "many drymarias" is also an approved form. By the same token, one should write Chester soils, Chernozem soils, and Podzol soils; but Chester loams, chernozems, and podzols.

Ordinary adjectives and particularly those words that are appended to the names of genera are commonly used to designate plants or animals of particular species. To illustrate: Black walnuts (trees of the species *Juglans nigra*); white oak (of the species *Quercus alba*); ponderosa pines (of the species *Pinus ponderosa*); and Rothrock grama (grass of the species *Bouteloua rothrockii*).

Class names of species and genera are always singular, whereas the names of classes of higher categories in the various scientific classifications may have either the plural or the singular form. But in each case the meaning of a class word must be singular, owing to the fact that the meaning is applied identically to all the individuals represented. To illustrate: *Beta vulgaria* (sing. form), *Citrus* (sing.), *Miami loam* (sing.), Leguminosae (pl. form), Protozoa (pl.), Chernozem (sing.), and Podzol (sing.). The name "Leguminosae" stands for all plants of that class, but its meaning must be identical for each leguminous plant. Hence, the word "Leguminosae," although plural (Latin) form, names a general concept whose meaning is the same for each member of the class.

NOTE

IMPROVED RASP FOR SECURING PULP FROM SUGAR BEETS FOR ANALYSIS[1]

FOR determination of sucrose percentage and apparent purity coefficient, finely-divided pulp is rasped from the sugar beet root commonly by a disk rasp. In the method followed at certain factories and at the field stations of the Division of Sugar Plant Investigations, the washed or cleaned sample of roots is weighed and then each root of the sample is split approximately into halves by a saw or knife. One set of half roots is rasped to secure a composite pulp sample, the other set of half roots being discarded. In practice, the half beets from which pulp is to be rasped are placed longitudinally on a belt

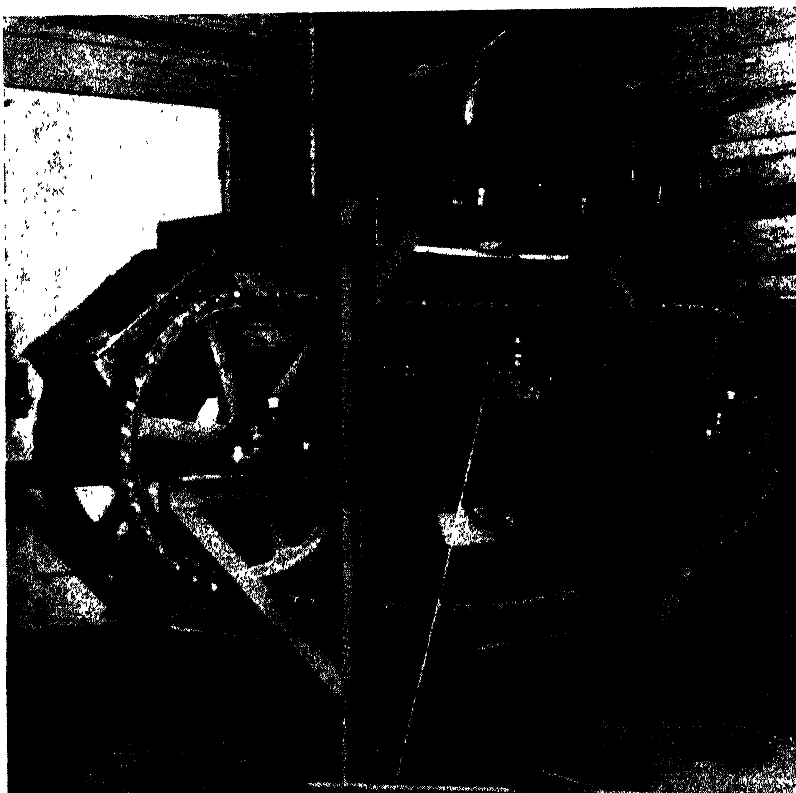

FIG. 1.—Beet rasping machine. The disk rasp carried on the central shaft cuts the pulp from the beet roots carried over it in the carrier boxes. The foot lever lowers a scoop holder to permit the removal of the scoop which contains the composite pulp sample. (Photographed by Mr. E. E. Patton of the Farmers & Manufacturers Beet Sugar Association).

[1]Cooperative investigations with the Michigan Agricultural Experiment Station.

studded with sharp points to hold them firmly. The belt then carries the half roots to the rapidly revolving disk rasp which cuts a radial sector from crown to tip of each, the pulp being thrown onto a wide semicircular band.

The basic idea embodied in the machine[2] which has been devised is that the whole sugar beet roots comprising the sample, after being washed or cleaned, are individually placed in carrier boxes which move over the disk rasp in such a manner that a radial sector is removed from each root. The machine has the advantage of making unnecessary the splitting of the roots of the sample, an operation which in sugar analysis procedure usually requires the time of one man. The whole roots after sampling commonly are accepted by the sugar factory, whereas half or quarter beets may be refused as not usable.

The machine as described (Fig. 1) has been constructed at the Michigan field station of the Division of Sugar Plant Investigations. Mechanical drawings showing construction of this machine are being prepared and copy may be had by anyone interested.—J. G. LILL, *Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, East Lansing, Michigan.*

[2]The first machine of this type was developed by Mr. Ninegar of the Great Western Sugar Company. Machines based on the same idea were later built by Mr. H. L. Busch of the National Seed Company and Mr. C. E Cormany of the Holly Sugar Corporation.

AGRONOMIC AFFAIRS

CROPS SECTION PROGRAM, 1940

TENTATIVE arrangements for the 1940 programs of the various Crops Sub-sections are announced by Dr. S. C. Salmon, Chairman of the Crops Section, as follows: A joint symposium with Soil Fertility and Soil Chemistry on "The Relation of Soil Type and Soil Treatment to Quality and Composition of Crops," under the leadership of Dr. W. H. Metzger for Soils and Dr. C. J. Willard for Crops; a symposium on weed control, under the leadership of Dr. C. J. Willard; four symposia on various phases of breeding sorghums and small grains, under the general leadership of Dr. P. C. Mangelsdorf, with Dr. K. S. Quisenberry arranging for those relating to wheat; Grassland Agriculture, under the leadership of Dr. O. S. Aamodt.

It is anticipated that there will be held a general crops session for all sub-sections, with a brief program and a business meeting. Several sessions are being held open for volunteer papers and it is urged that all who contemplate the presentation of such papers submit titles to the Chairman of the Section at an early date. It is probable, also, that provision will be made for one or more informal round-table discussions relating to subjects of interest to small groups.

THE 1939 PROCEEDINGS OF THE SOIL SCIENCE SOCIETY

FOLLOWING regrettable delays, some of which were beyond the control of the Editor, proofs are now beginning to go out to the authors on the 1939 volume of Proceedings of the Soil Science Society. Part of the delay has been due to the decision to print the volume by letterpress instead of using the offset process employed heretofore. Before arriving at this decision, it was necessary to have all copy in hand in order to arrive at a reasonable close estimate of cost of publication. In the earlier volumes where this question did not enter in, it was possible to begin work as soon as copy was received regardless of whether the complete manuscript for all Sections was available.

Most of the type has been set on Volume 4 and it is confidently expected that the volume will now move along rapidly to completion. We hope that the improved appearance of the volume will compensate, to some extent at least, for the delay experienced this year. If this method of publication proves satisfactory, it will be possible to move Volume 5 much more expeditiously.

ALFALFA IMPROVEMENT CONFERENCE

THE Eighth Alfalfa Improvement Conference will be held at Fort Collins, Colorado, July 8 and 9.

Workers in charge of the experiments at the Scotts Bluff Field Station, Mitchell, Nebraska, will be available July 6 to explain the research program at that station.

MEETING OF THE WESTERN BRANCH OF THE SOCIETY

THE Western Branch of the American Society of Agronomy will hold its annual meeting for 1940 on July 11, 12, and 13, at Logan, Utah. These dates were chosen to harmonize with the regional alfalfa

conference to be held at Fort Collins, Colorado, just prior to the Branch meetings and the regional grass conference to be held in this area immediately after the Branch meetings.

Response to a questionaire sent out some time ago indicated that very interesting papers will be presented and a good attendance is expected.

BIBLIOGRAPHY OF LITERATURE ON POTASH AS A PLANT NUTRIENT

UNDER the above title the American Potash Institute, Inc., Washington, D. C., has issued the first of a series of lists of references to the literature on the subject. The first contribution covers literature reviewed from July 1 to September 30, 1939. The material is presented in three sections, namely, by crops, by subject under potash, and under soils, and is supplemented with a subject and author index.

According to a notice accompanying the first number, it is proposed to issue several numbers of the Bibliography per year to be sent gratis to those requesting it.

CHANGE IN DATE OF SUMMER MEETING OF CORN BELT SECTION

THE summer field meeting of the Corn Belt Section of the American Society of Agronomy is now scheduled for September 9 and 10 at Iowa State College instead of 4, 5, and 6, as reported in the April issue of the Journal. It was determined that this change is desirable in the interest of the expanded Grassland Conference program, scheduled for the campus at Ames on September 11.

Inspection of work at the Agronomy Farm south of the campus, will start at 1:30 on Monday. A dinner and short program at 6:30 will be followed by group conferences at 8:00, with special emphasis on plot design and statistical analyses. Tuesday at 8:00 field inspections will be continued and at 11:00 groups will leave Ames to see work in other parts of the state.

The Regional Grassland Conference program will get underway at 9:30 on the 11th, continuing through the afternoon and evening. The conference of technical workers, as carried out at the Ohio meeting last year, has been expanded for this year with agricultural leaders in all related fields invited to participate. The conference is sponsored by the Pasture Committee of the Agronomy Society and by the Association of North Central Agricultural Experiment Station Directors.

NEWS ITEMS

FRED K. CRANDALL, Assistant Agronomist at the Rhode Island Agricultural Experiment Station, died on May 31.

A JOINT meeting of the Florida State Florists Association and of the Soil Science Society of Florida was held at the University of Florida, May 28, 29, and 30, with Dr. S. A. Waksman as the principal speaker on the general program. Symposia were also held on soil organic matter and micro-elements in Florida agriculture. Dr. Michael Peech of the Lake Alfred Substation was elected president for the coming year and Dr. R. V. Allison, head of the Soils Department at the University of Florida, the retiring president, was named secretary-treasurer.

SURPLUS copies of the TRANSACTIONS of the Third Commission of the International Society of Soil Science have been transferred to Geneva, N. Y., and placed in storage with other soils and agronomic publications distributed by the Soil Science Society and the American Society of Agronomy. Volume A of the TRANSACTIONS contains the formal papers given at the New Brunswick, N. J., meeting, while Volume B contains the program, list of participants, a report of the discussion of the papers, and other incidental material. Both volumes are paper bound and are available for $2.00 for the two volumes, post paid.

THE CANADIAN SEED GROWERS' ASSOCIATION and the Canadian Society of Technical Agriculturists met in joint sessions at the University of Manitoba, June 17 to 22.

THE WORKS PROGRESS ADMINISTRATION has issued a limited edition of Volume III of its "Index to Research Projects" undertaken under the auspices of the Administration.

THE IMPERIAL BUREAU OF PASTURES AND FORAGE CROPS at Aberystwyth, Great Britain, has issued the following bulletins in its Herbage Publication Series: Bulletin 27, "The Control of Weeds," edited by R. O. Whyte, 168 pages, illustrated, price 7s. 6d. Bulletin 28, "Technique of Grassland Experimentation in Scandinavia and Finland," 52 pages, illustrated, price 2s. 6d. Bulletin 29, "Grassland Investigations in Australia," 107 pages, price 5s.

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THE VALUE IN HYBRID COMBINATIONS OF INBRED LINES OF CORN SELECTED FROM SINGLE CROSSES BY THE PEDIGREE METHOD OF BREEDING[1]

I. J. JOHNSON AND H. K. HAYES[2]

THE utilization of inbred lines of corn in hybrid combinations has been studied extensively by many investigators. Most of the inbred lines used in these studies, however, have been obtained by self pollination and selection from commercial varieties. Recently, Hayes and Johnson (2)[3] and Wu (6) at the Minnesota Station have presented the results of breeding improved inbred lines by what was designated as the pedigree method of breeding. As the method was described in considerable detail in these earlier publications, it seems unnecessary to summarize here in great detail. Inbreds were selected from single crosses between inbreds obtained from commercial varieties. Each of the nine crosses from which inbreds were selected was made for the purpose of combining the desirable characters of the parental inbreds and after crossing selection in self-pollinated lines was practiced from F_2 to F_6 before the new inbreds were considered sufficiently homozygous to be ready for use in hybrids. During the segregating generations selection was made for ability to withstand lodging and for resistance to smut as well as for general plant vigor. Inbreds obtained by this method of breeding are much superior in ability to withstand lodging to those obtained by selection from Minnesota open-pollinated varieties. Before testing the new inbreds in single and double crosses they were tested in inbred-variety crosses with Minn. No. 13. Previous investigations (3, 4, 5) of inbred-variety crosses have led to the general acceptance of this method as a means of discarding lines of low combining ability.

The present study was made to determine the relation between the performance of inbreds in inbred-variety crosses and in single crosses. Since crosses were made also between lines of diverse as well as some-

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[3]Figures in parenthesis refer to "Literature Cited," p. 485.

what similar origins, additional data are presented to show the value of genetic diversity in origin of inbred lines in relation to their yields in single cross combinations.

MATERIALS AND METHODS

The inbred-variety crosses were studied in replicated plot trials grown in three localities in 1936 and 1937 as has been described in considerable detail by Wu (6). The yields of these inbred-variety crosses were corrected to the regression of yield on moisture, the correlation coefficient for the relation between yield on a 14% moisture basis and moisture percentage of ears at husking being $+.315 \pm .086$. The corrected yields were expressed as percentages of the average yield of Minn. No. 13 and Minhybrids 401 and 402 and were placed in four groups for yielding ability, group 1, 80 to 89; group 2, 90 to 99; group 3, 100 to 109; and group 4, 110 or more.

Single crosses made between selected inbred lines were tested in 1939 in several representative areas of the state to which they were adapted. The northern group of early maturing single crosses were grown in three replications at each of four locations, *viz.*, University Farm, St. Paul; North Ottertail County; Todd County; and Clay County. This gave an opportunity to compare single crosses from unrelated inbreds with single crosses between inbreds with 1% in common as explained by Hayes and Johnson (2). In these trials there were 19 single crosses between unrelated inbreds classified on the basis of top cross performance in groups 3×3, 3×4, and 4×4 and 14 single crosses between related inbreds with one parent in common. These crosses were tested in three groups of randomized block trials with not more than 24 varieties per block and including Minhybrids 401 and 402, previously known to be outstanding in yield performance (1). In these studies Minhybrid 401 gave an average yield on a 14% moisture basis of 48.2 bushels with a moisture content at husking of 25.9%, while Minhybrid 402 yielded 43.7 bushels with a moisture content at husking of 21.6%. The difference in yield was 4.5 bushels and in moisture content 4.3%. As some of the hybrids were earlier than Minhybrid 402, a calculated standard yield and moisture percentage were used to compare with the early hybrids by assuming a direct reduction of a bushel in yield below Minhybrid 402 for each reduction of 1% in moisture content at husking.

The yields of single crosses were compared with Minhybrids 401 or 402 or the calculated standard and placed in frequency distributions based on from minus 6 to plus 5 times the standard error of a difference. Thus in group 1 the calculated standard error of a mean obtained from the analyses of variance was 1.2 bushels for the average of the four locations. The standard error of a difference was 1.9 bushels and the class centers for plus and minus differences were 1.9, 3.8, 5.7, 7.6, and 9.7 bushels for the standard error of a difference multiplied by 1 to 5, respectively. The yield of each single cross was compared with a standard and entered in the frequency table according to the extent of its difference from the standard.

In the north central group of single crosses grown at three locations, University Farm, St. Paul; Meeker County; and the Morris branch station, there were 12 single crosses between groups 1×1 or 1×2 as classified by the yielding ability of the inbred-variety crosses, 14 single crosses of groups 1×3 or 1×4, and 28 single crosses from groups 2×3 or 2×4. In these trials Minhybrid 402 yielded an average of 61.9 bushels with a moisture percentage at husking of 17.5%. Minhybrid 401

yielded 66.1 bushels with a moisture content at husking of 20.8% and Minhybrid 301 yielded 77.0 bushels with a moisture content of 23.1%. There were only a few single crosses as late as Minhybrid 301 and these were compared with 301. Intermediate standards for moisture content between that of Minhybrid 301 and 401 or 401 and 402 were calculated by averaging the yields and moisture content of the appropriate hybrids. As there were a few hybrids earlier than 402 calculated standards were obtained as explained for the northern group. The yield of each single cross was compared with a standard of similar moisture content at husking.

Medium maturing single crosses were tested in central Minnesota in four locations, *viz.*, at University Farm, St. Paul; the Morris branch station; Stearns County; and South Ottertail County. These included 10 single crosses from unrelated parentage from groups 2×3 or 2×4, 64 single crosses from unrelated parentage from groups 3×3, 3×4, or 4×4, and 24 single crosses from related inbreds with one parent in common from groups 3×3, 3×4, or 4×4. In these studies the crosses were compared directly with a standard hybrid of similar moisture content or with the average of 401 and 301 or 401 and 402. Average yields and moisture percentage of Minhybrids 402, 401, and 301 were 55.5 bushels with a moisture percentage of 19.5 for 402, 60.7 bushels and 24.7% moisture for 401 and 64.3 bushels with 27.6% moisture for 301.

EXPERIMENTAL RESULTS

As previously explained, the average yield of each single cross was compared with the yield of an appropriate standard for similar moisture content at husking, based on the moisture content and yield of the standard Minhybrids 401, 402, or 301. This may be illustrated in detail by three crosses grown in central Minnesota. The yields and moisture content of these crosses are as follows:.

Percentage yield of inbred parents in inbred-variety crosses	Yield of single crosses, bu.	Moisture content of crosses, %
110 and 120	60.4	26.6
110 and 112	63.7	23.9
112 and 122	59.8	20.2

Yields in bushels per acre and moisture percentage at husking of the standard hybrids in this trial were as follows:

Standard hybrid	Yield, bu.	Moisture, %
Minhybrid 402	53.5	19.4
Minhybrid 401	60.4	23.9
Minhybrid 301	62.9	27.6
Average, 401 and 402	57.0	21.7
Average, 401 and 301	61.7	26.0

The computed standard error of a difference, by an analysis of variance, for these trials was 2.36 bushels. Each of the crosses was then compared with the appropriate standard by obtaining the difference in yield between the standard and the cross concerned, and entered in the correct frequency distribution with class centers at 0, + or

−1, + or −2, etc. The 0 class contained all deviations lying from 0 to plus or minus 1.1, class 1 from 1.2 to 3.5, class 2 from 3.6 to 5.9, etc.

The cross that yielded 60.4 bushels with moisture content of 26.6% was compared with the average of 401 and 301 giving a lower yield than the standard of 1.3 bushels which placed it in the frequency class for −1 times the standard error of a difference. The second cross with a yield of 63.7 bushels and a moisture content of 23.9% was compared with Minhybrid 401 giving an increase in yield of +3.3 bushels which placed it in the frequency class for +1, while the third cross was compared with Minhybrid 402 giving an increase in yield of 6.3 bushels placing it in the frequency class for +3.

The summary of results for the single crosses grown in each of the three locations and classified for yield as shown above is given in Table 1.

Comparisons of these results will not be made in great detail. In the North Central region there were 12 single crosses between inbreds belonging to inbred-variety groups 1 or 2. The mean deviation of this group was −0.50±0.66. The 28 single crosses of group 2 with groups 3 or 4 gave an average mean deviation of +1.61±0.68. The difference between these two types of crosses was 2.11±0.95. In the central location single crosses of unrelated parentage gave an opportunity to compare 10 crosses of groups 2×3 or 2×4 with 64 crosses of groups 3×3, 3×4, or 4×4. The mean difference was 0.74±0.46. These results give some evidence that the yielding ability of inbred lines in inbred-variety crosses is not closely related to average combining ability in single crosses when inbred parents are widely dissimilar in origin. As all single crosses were compared with appropriate standard double crosses it seemed desirable to combine the comparisons for the three locations to obtain a larger number of crosses within each group.

The data from the three locations were combined in a single frequency table giving an opportunity to compare the yielding ability of the single crosses with an appropriate standard double cross of similar maturity. The crosses were classified also into groups on the basis of the combining ability of the parents in inbred-variety crosses, as has been explained. Groups 1 and 2 with inbred-variety cross yields from 80 to 99 were considered as low combiners, while groups 3 and 4, yielding from 100 to 122, were considered as high combiners. The data from crosses of unrelated inbreds are given in Table 2.

The 12 single crosses from inbred parents both classified as low combiners gave a mean deviation of −.50±0.66 and the 52 single crosses between inbred lines in which one parent was classified as low and the other as a high combiner gave a mean deviation of +1.06 ±0.42. The difference between these two groups of crosses of 1.56± 0.78 may be considered to be significant. The 52 single crosses between groups, designated low×high, gave the same mean, 1.06±0.42, as the 83 crosses from yielding groups of high×high with a mean of 1.14±0.24.

From the data given in Table 2 summarizing the distribution of yields from 147 single crosses between inbred lines of unrelated origin,

TABLE 1.—*Frequency distribution of single cross yields when compared with recommended Minnesota hybrids of similar maturity in relation to the inbred-variety cross combining ability of their inbred parents classified into groups 1, 2, 3 and 4 based on percentage yield in inbred-variety crosses of 80–90, 90–99, 100–109, and 110 or above, respectively.*

Group of inbred parents	Location of trials	Class centers of plus and minus 1 to 8 times the S.E. of a difference																	Total	Mean class
		−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8		
Unrelated 1×1 or 1×2......	North Central	—	—	1	—	—	1	1	1	4	2	2	—	—	—	—	—	—	12	−0.50±0.66
Unrelated 1×3 or 1×4......	North Central	—	—	—	1	—	—	—	3	1	5	2	—	1	—	1	—	—	14	+0.79±0.68
Unrelated 2×3 or 2×4......	North Central	—	1	1	1	—	—	2	2	2	1	5	3	5	3	1	—	1	28	+1.61±0.68
Unrelated 3×3, 3×4 or 4×4.	Northern	—	—	—	—	—	—	—	1	1	1	2	8	4	2	—	—	—	19	+2.84±0.35
Related 3×3, 3×4 or 4×4...	Northern	—	—	1	—	2	3	2	3	—	2	—	1	—	—	—	—	—	14	−1.79±0.63
Unrelated 2×3 or 2×4......	Central	—	—	—	—	—	—	1	3	3	2	1	—	—	—	—	—	—	10	−0.10±0.38
Unrelated 3×3, 3×4 or 4×4	Central	—	—	—	1	1	4	5	6	7	18	12	6	2	2	—	—	—	64	+0.64±0.26
Related 3×3, 3×4 or 4×4...	Central	—	—	—	2	2	—	8	4	4	1	2	1	—	—	—	—	—	24	−1.25±0.42

TABLE 2.—*Summary of frequency distribution of single cross yields at all locations when compared with recommended Minnesota double crosses of similar maturity in relation to the inbred-variety combining ability of their inbred parents.*

Type of cross	Class centers of plus and minus 1 to 8 times the standard error of a difference																	Total	Mean class
	−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8		
Low×low...........	—	—	1	—	—	1	1	1	4	2	2	—	—	—	—	—	—	12	−0.50±0.66
Low×high..........	—	1	1	2	—	—	3	8	6	8	8	3	6	3	2	—	1	52	+1.06±0.42
High×high.........	—	—	—	1	1	4	5	7	8	19	14	14	6	4	—	—	—	83	+1.10±0.24

a total of 63, or 43%, yielded significantly higher than a recommended standard double cross of comparable maturity. This unusually high percentage of successful combinations would suggest that the pedigree method of breeding inbred lines of corn not only has been of distinct value in the production of inbred lines with desirable agronomic characters but likewise offers an opportunity to impart to those inbred lines unusually high combining ability as measured by single cross yields. This property is undoubtedly associated with the large degree of genetic diversity between inbred lines selected from divergent sources and would be expected to occur on the basis of the Mendelian explanation of heterosis.

Additional information on the relation between the genetic diversity of inbred lines and their yields in hybrids in given in Table 3. Since the inbred-variety cross performance of the two groups of lines used in these crosses was similar (groups 3 and 4), the principal difference between the two groups of crosses is the extent of similarity in their parentage. The "related" inbred lines were obtained by selection in the segregating progeny from crosses between inbred lines and were combined in such a manner that one of the parents of the original single crosses was in common in each of the two original crosses from which the inbred lines were selected.

TABLE 3.—*Frequency distribution of single cross yields when compared with recommended Minnesota hybrids of similar maturity in relation to the extent of genetic relationship of their inbred parents.*

Relationship of inbreds	Class centers of plus and minus 1 to 7 times the standard error of a difference														Total	Mean class
	-6	-5	4	- 3	-2	-1	0	1	2	3	4	5	6	7		
Unrelated........	—	1	1	4	5	7	8	19	14	14	6	4	—	—	83	+1.14±0.24
Related.........	1	2	4	3	10	7	4	3	2	2	—	—	—	—	38	−1.45±0.35

There were 83 single crosses between unrelated inbreds and 38 between related inbreds, the mean deviations of the yield of single crosses from the two types of crosses being +1.14±0.24 and −1.45±0.35, respectively, or a highly significant difference.

SUMMARY OF RESULTS

1. In a study of single crosses between inbred lines bred by the pedigree method from single crosses, a comparison was made between their inbred-variety cross and single cross performance.

2. The evidence obtained from 12 single crosses between relatively low combining inbreds indicates that single crosses between low combiners may be expected to yield somewhat lower, on the average, than single crosses from relatively high combining inbreds when the single crosses are made between inbreds of diverse genetic origin. Single crosses between low combining inbreds with high combiners yielded as well, however, as single crosses between high combiners. The proportion of high yielding single crosses from low×high combiners was as good in this study as from high×high combiners.

3. Additional data from crosses between related inbred lines indicate that diversity in genetic origin is an important factor in obtaining the maximum expression of hybrid vigor.

4. From a comparison of 147 single crosses between inbreds of unrelated origin with recommended double crosses, 63, or 43%, yielded significantly higher than the double crosses used as a standard. These results indicate the desirability of selecting inbreds for use in double crosses from crosses between inbred lines that have superior characters, thus giving an opportunity to combine in a single inbred the desirable characters of its two parents.

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THE TESTING OF BUFFALO GRASS "SEED", *BUCHLOE DACTYLOIDES* ENGELM[1]

Mildred M. Pladeck[2]

BUFFALO grass is one of the chief components of the grassland vegetation of the Great Plains area. This plant, because of its low-growing, stoloniferous habit, forming dense and extensive ground cover, is of great value for grazing and in soil conservation. Under favorable conditions a single plant produces numerous radial stolons which root at the many nodes. It is dioecious (4)[3] and occasionally monoecious (1), but at times bears a few perfect flowers on the staminate spike (3, 6). The staminate and pistillate inflorescences are borne on separate plants or separate branches which propagate their own kind. The fruit or "bur" consists of one or two to four spikelets whose glumes have become hardened and fused about the loose grains.

According to Savage (5), the seeds usually germinate poorly, a statement needing confirmation. A poor stand of buffalo grass from seed, according to the evidence herein presented, may be due to (a) early harvesting of the seed, (b) low purity, and (c) low caryopsis count.

Early harvest.—When burs were immature, or mature but not weathered, germination was found to be very low. When, however, burs were weathered, thereby indicating a long period on the ground, and harvested late in the fall, during the winter, or early spring, germination within 10.0% of the caryopsis count was usually obtained. (See Table 1.)

Low purity.—Inasmuch as the burs of buffalo grass must be harvested from on or close to the ground, large amounts of debris apparently of similar bulk and specific gravity, form a major part of the bulk seed under the present methods of harvesting. The average purity of seed harvested in 1937 and winter of 1938 was 34.02%, that of the 1938 harvest 29.63%, and that of 1939 (one sample) 41.51%.

Low caryopsis count.—As the purity figure represents the percentage of burs and cannot include a separation of the number containing caryopses and those which are empty, or completely necrotic, the caryopsis count reduces the amount of pure live seed still further. The germination can be predicted within 10.0% of caryopsis count, provided that the seed has been harvested after it has received some degree of weathering. The average count of the 1937 (and winter of 1938) seed was 72.16%, and that of the 1938 harvest 57.69%.

Thus it is the low purity (the result of harvesting difficulties) and caryopsis count which, according to the evidence herein presented,

[1]Contribution of the San Antonio, Texas, Seed Laboratory, No. 1. The earlier tests were carried on in the Division of Seed Investigations, Bureau of Plant Industry, Washington, D. C., during 1935–36. The later tests were made at the Soil Conservation Service Seed Laboratory, San Antonio, Texas. The cooperation and suggestions of the personnel of both laboratories, of the SCS Nursery Division, and of Mr. H. B. Parks, Chief, Texas State Division of Apiculture, are gratefully acknowledged. Received for publication February 19, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 494

TABLE 1.—*The percentage of purity, caryopsis count, degree of weathering, and germination of buffalo grass from various localities.*

Lab. No.	Date of harvest	State	Appearance of burs	Percentage purity	Percentage burs with caryopses	Percentage of germination	
						Check*	Highest†
			Harvest of 1935‡				
271117	Mar. 21, '35§	Texas	Weathered	—	—	66.7	—
258113	June 26, '35	Texas	Slightly green	—	80.0	3.5	47.0**
758114	Mar. – '35	Texas	Weathered	—	88.0	46.7	78.0
758304	Aug. '35§	—	—	—	78.0	19.3	61.3**
758409	Sept. '35§	Okla.	Diseased	—	12.0	16.0	—
758307	Aug. '35§	S. Dak.	Barely mature	33.58	80.0	16.5	65.0**
758476	Aug. 26, '35	Kansas	—	92.0	—	58.0	58.0
759304	Nov. 29, '35	Kansas	Weathered	—	—	82.0	82.0
		Harvest of 1937 to February 1938					
S–74	July 24, '37	Texas	Weathered	8.90	78.0	34.0	66.5**
S–197	Aug. 14, '37	Texas	Partly weathered	27.40	76.0	58.0	70.5**
S–198	Aug. 14, '37	Texas	Partly weathered	33.20	76.0	52.0	73.0**
S–199	Sept. 30, '37	Texas	Partly weathered	19.65	54.0	51.5	55.0**
S–205	Sept. 30, '37	Texas	Partly weathered	60.67	85.3	32.0	83.0**
S–229	July 17, '37	Texas	Partly weathered	69.12	76.5	55.2	75.0**
S–249	Jan. 31, '38	Texas	Weathered	22.03	61.0	51.5	58.7**
S–250	Feb. 28, '38	Texas	Weathered	31.22	72.0	61.5	61.5
Averages				34.02	72.4	49.5	67.9
			Harvest of 1938				
S–295	Aug. 16, '38	Texas	Mostly weathered	26.51	56.14	9.5	46.5**
S–297	Aug. 16, '38	Texas	Mostly weathered	21.65	36.97	33.0	39.5**
S–302	Sept. 17, '38	Texas	Partly weathered	30.43	68.2	46.0	55.7**
S–303	Sept. 17, '38	Texas	Mostly weathered	17.25	69.0	39.5	65.8**
S–606	Oct. 29, '38	Texas	Partly weathered	52.32	58.15	47.5	54.5**
Averages				29.63	57.69	35.1	52.4

*Check test germinated at room temperature to 35° C alternation. Room temperature, 17 hours; 35° C, 7 hours.

†Highest germination obtained by any method is indicated to show that germination within 10.0% of the caryopsis count, or within the germinating capacity of the sample, can be obtained although special treatments may be required. There are approximately 52,000 burs per pound.

‡Data incomplete because of small size of samples. In most cases the seed was entirely used for germination tests before the value of other characteristics mentioned above was realized. Samples were tested in the Division of Seed Investigations, Bur. of Plant Industry; submitted by Division of Forage Crops and Diseases or by Soil Conservation Service.

§Date received. **Chilled.

would warrant more attention than germination in determining the establishment of buffalo grass from seed because they are less easily controlled. The actual germination itself can be controlled by harvesting the seed when sufficiently weathered.

DISEASES

In making purity tests, the presence of a few to many grayish weathered and enlarged axillary buds was observed in nearly all samples received. Upon sectioning these were found to contain nematode sacs filled with dormant living nemas. The nematode galls were first observed on living buffalo grass on February 22, 1937, at the San Antonio Nursery. Most of the galls occurred in the deformed nodal buds at the ground line, although a few were observed 4 to 5 inches up from the base of the plants. The buds in which the nematode sacs occurred were apparently killed, since no further development of the buds into normal stolons or fruiting branches occurred. However, other healthy buds from the same nodes produced normal growth. The living galls usually contained a large number of larval and two or more adult nematodes. According to G. Steiner of the U. S. Bureau of Plant Industry, the nematode form is a new *Anguina* species and will be described by him in the near future.

That the disease is widespread, at least in Texas, is evident from the following list of counties from which specimens are now on hand: Bell, Bexar, Coryell, Dallas, and Williamson. The disease was also reported from Oklahoma by Gernert (2).

The economic importance of the parasite has not yet been determined and the diseased patches thus far observed only in the spring have been small.

After many tests of buffalo grass seed in the laboratory, the writer has found no evidence that the germination itself was directly affected by the presence of nematode galls in samples tested, but rather indirectly as staminate and pistillate inflorescences were aborted and the set of seed consequently reduced in a given stand.

Other parasitic organisms found on buffalo grass samples examined to date included the following fungi: *Phyllachora graminis* (P) Fckl.; *Cercospora seminalis* E. & E.; *Helminthosporium inconspicuum* C. & E. *var Buchloe* E. & E.; *Alternaria sp.*; and Witchbroom (organism as yet undetermined).

One sample of burs from Stillwater, Okla., showed a 64.0% infection with *Helminthosporium inconspicuum*.

PURITY DETERMINATION AND CARYOPSIS COUNT

The purity of the buffalo grass seed tested by the laboratory was very variable for the reasons outlined under "low purity." The drop in the average purity of the 1938 lots, as compared with those of 1937, was probably caused by the extreme drought of that year. The lowest purity of the 1937 harvest was 8.9%, the highest 69.12%, and the average 34.02%. The lowest purity of the 1938 harvest was 17.25%, the highest 52.32%, and the average 29.63%.

The drought also affected the set of caryopses, thereby reducing the average percentage of filled burs from 72.16 (1937) to 57.69

(1938). The lowest percentage of filled burs in 1937 samples was 54.0; the highest 85.3. The lowest percentage of filled burs in 1938 samples was 36.97; the highest 69.0. A comparison of average percentages of the maximum germination obtained from each sample and the average caryopsis counts both for 1937 and 1938 showed a close agreement. The 1937 caryopsis count of 72.4% agreed within 10.0% with the germination of 67.9%. The 1938 caryopsis count of 57.69% agreed with the germination of 52.4%.

A further point of interest in connection with the caryopsis count was the number of caryopses contained in each bur. For this examination 50 burs from each of five samples and 170 burs from a sixth sample were dissected (after soaking in water for 3 hours). The following proportions were obtained: Burs with sound caryopses, 66.5%; burs entirely empty, 10.6%; and burs entirely diseased, 22.9%. The percentage of burs with one or more grains diseased was 10.9. Of the burs with sound caryopses (average of four samples) there were 24.0% with one sound caryopsis, 43.0% with two sound caryopses, and 14.5% with three to four sound caryopses.

Of the burs which contained both healthy and diseased caryopses, the sound caryopses germinated normally and were not affected by the presence of the diseased grains.

GERMINATION

During 1935–36, while the writer was stationed at the Federal Seed Laboratory in Washington, D. C., for the first time a number of samples of buffalo grass seed were received for test. Since no methods of testing this seed were available, trials with various temperatures and substrata were made.

Burs were tested in Petri dishes, in quadruplicates of 100, 2×100, or in a few instances, 2×50 seeds, by any one method, depending on the amount of seed available. Tests were incubated at one or more of the following alternations: 15°–25° C, 10°–35° C, 20°–30° C with daylight, 20°–35° C, room temperature (approximately 20° C)–35° C, and room temperature–30° C, with a daily exposure of 7 hours to the higher temperature and of 17 hours to the lower temperature. Additional tests were made in the greenhouse. As germination was more consistently higher at the room–35° C or 20°–30° C daylight alternations, the room–35° C temperature alternation was chosen as the "check" because exposure to daylight (favorable to the germination of most grasses) was possible, because speed of germination was increased with the slightly higher temperature, and because tests incubated at the 20°–30° C daylight alternation frequently suffered from the excess moisture present in a daylight germinator.

In addition to tests at the above temperatures, the effect of pre-chilling (at 3°–5° C) and of chilling (at 3°–5° C) after a period at higher temperatures were studied (Table 2). Sample 758113, which was immature and greenish in appearance, germinated 3.5% without pre-treatment. When chilled for 3 months this percentage was increased to 36.0. In another test pre-chilled for 1 month 47.0% of the burs sprouted. Sample 758304, with a germination of 19.3% without pre-treatment, showed an increase to 61.3% after 3 months' chilling.

TABLE 2.—*Effect of chilling on the germination of a sample (No. 758307) of buffalo grass which was mature but not weathered.**

Date tested	Method†	Percentage of sprouts		Total germination %
Aug. 29, '35	20° 30° C DL, soil	7.5	Then chilled 3 mo. at 5° C	37.0
Sept. 19, '35	Room 35° C toweling	6.0	Then chilled 3 mo. at 5° C	48.5
			Laboratory	Greenhouse
Oct. 3, '35	Soaked overnite:			
	In KNO_3		7.0	14.5
	In H_2O		11.5	22.0
	Check		6.0	12.5

October 17, 1935

Treatment	Temperature and method	Percentage of germination	
		Soil	Peat and soil
Check (none)	15° C	1.5	1.0
Check	20°–30° C DL	11.5	8.5
Check	Room 35° C	28.0	13.0
Stratified:			
2 weeks at 5° C	Room-35° C	14.0	13.5
3 weeks at 5° C	Room–35° C	16.0	14.0
4 weeks at 5° C	Room–35° C	21.5	16.5
2 months at 5° C	Room-35° C	29.0	32.0
3 months at 5° C	Room-35° C	31.0	50.0
2 weeks at 10° C	Room-35° C	18.0	11.0
3 weeks at 10° C	Room–35° C	15.5	9.5
4 weeks at 10° C	Room–35° C	25.5	21.0
2 months at 10° C	Room 35° C	21.0	26.0
3 months at 10° C	Room–35° C	48.0	26.0

February 11, 1936

Treatment	Germination temperature					
	Room–35° C		15°–25° C		Room–30° C	
	Soil	Peat and soil	Soil	Peat and soil	Soil	Peat and soil
Check (no treatment)	16.5	17.5	8.0	6.0		
Stratified at 5° C:						
1 month	9.0	24.5	25.0	11.5		
2 months	65.0	49.5	50.0	36.0		
3 months	46.0	61.0	—	—	52.5	57.5
4 months	54.0	63.0	—	—	43.5	51.0‡
6 months	34.0	54.0	—	—	34.5	39.0

*All tests germinated 4×50 in Petri dishes at temperatures as stated. Room temperature was approximately 20° C from Aug. to Oct.; lower in Feb.

†DL = Daylight, 7 hours; 20° C, 17 hours. Room-35° C. Room, 17 hours; 35° C, 7 hours.

‡Quadruplicates very variable.

A parallel pre-chilled test germinated 36.0%. Sample 758307, mature but not weathered, fluctuated from 6.0% to 28.0% germination without pre-treatment; and from 29.0% to 65.0%, with 2 to 6 months' chilling (Table 2). Samples 271117, 758114, and 759304, weathered in appearance, germinated 66.7%, 74.7%, and 82.0%, respectively, without chilling.

The effect on weathered burs of pre-soaking overnight in tap water or in a 0.2% KNO_3 solution was in one instance definitely stimulating to germination. Among unweathered lots there was no increased response. More recent pre-soaked tests of weathered seed indicated in some cases a favorable reaction (Table 3).

The type of substratum was found in early tests to be especially important to the germination of buffalo grass. A Room–35° C test using toweling (sample No. 271117) as the substratum yielded 35.5% of sprouts. When the seed remaining ungerminated was transferred to sterilized soil, germination increased to 64.0%. A parallel soil test germinated 66.7%. In another sample (No. 758114) the Petri-towel test produced 49.2% of sprouts and the soil test 64.5%. This stimulating effect produced by soil on buffalo grass germination is believed by the writer to be the result of a more favorable moisture relation between the seed and the soil.

As there were usually a variable number of burs containing sound caryopses remaining ungerminated at the termination of each test, a number of caryopses were removed and germinated. In one test (No. 271117) of 25 hulled grains, 13 germinated at once and 11 more after the pericarp was punctured. In another test of 33 dormant caryopses, all germinated when the pericarp was punctured. Thus it appears that the pericarp of dormant grains must be weakened by soil chemicals, temperatures, or organisms before germination can take place.

The indications from the treatments and methods employed in preliminary trials as outlined are that burs harvested from late summer to early spring, which appear to be well weathered, germinate far better and show fewer dormant caryopses than samples harvested green or barely mature. Since burs which were greenish or straw-colored in appearance did not germinate readily without considerable pre-treatment, the possibility that a period of weathering is essential in inducing maximum germination is suggested.

In the weathered samples the greatest number of sprouts occurred during the first week, some the second week, and only an occasional sprout thereafter. In chilled tests the maximum number of seedlings occurred during the first week after removal from the refrigerator. No germination occurred in the refrigerator either at 3°–5° C or at 10° C.

From these preliminary trials a definite schedule of procedure in testing buffalo grass was set up at the San Antonio Seed Laboratory. All burs were germinated in quadruplicates of 50 or 100 in a mixture of 1 part each of sterilized peat, sand, and local black soil in Petri dishes. The daily temperature alternation was 35° C from 9 a.m. to 4 p.m. and room temperature from 4 p.m. to 9 a.m. Check tests were germinated at this alternation with no pre-treatment. Chilled tests

were placed in the refrigerator at 3°–5° C for 4 days to 1 week, for 2 weeks, for 4 weeks, and some for 8 weeks, then germinated at the same temperature alternation as the check test. The duration of tests was 2 months.

During 1937 and 1938 the figures obtained for freshly harvested lots tested at the San Antonio Seed Laboratory followed the trend of germination of the Washington trials.

No conclusive data have yet been accumulated, because the wide variation in degree of maturity of the burs in a given sample and the difficulty in maintaining at all times a uniformity of moisture in the soil substratum were apparently responsible for variation in germination. Hence, all averages in Table 3 should be considered as tentative.

In 1937, the germination of the eight samples of buffalo grass harvested in Texas, which were weathered or partly weathered, averaged as follows:

Caryopsis count	72.4%
Germination of check test	49.7%
Germination after chilling 4 days to 1 week	51.0%
Germination after chilling 2 weeks	58.1%
Germination after chilling 4 weeks:	
Tested immediately	60.5%
Tested 2 months later	70.1%
Germination after chilling 8 weeks	70.3%

In 1938, the averages of five Texas samples tested were as follows:

Caryopsis count	57.7%
Germination of check test	35.1%
Germination after chilling 1 week	44.1%
Germination after chilling 2 weeks	44.7%
Germination after chilling 4 weeks	47.6%

Tests of 44 hand-gathered samples from Spur, Texas, which were immature, or mature but not weathered, gave the following averages:

Caryopsis count	78.68%
Germination of check test	3.18%
Germination after 1 month's chilling	9.61%

In addition, the average number of burs which produced one, two, or three to four sprouts per bur, obtained from the chilled tests of eight samples, was as follows:

Burs with 1 sprout per bur	38.5%
Burs with 2 sprouts per bur	23.9%
Burs with 3 or 4 sprouts per bur	4.3%
Total germination	66.7%

SUMMARY AND CONCLUSIONS

From the foregoing data, it is evident that the establishment of a good stand of buffalo grass from seed is strongly influenced by the character of the seed material. A poor seed set indicates a low percentage of burs which contain caryopses. Difficulty in harvesting

TABLE 3.—*The effect of various chilling treatments on the germination of buffalo grass.**

Lab. No.	Date harvested	Caryopsis count	Date tested	Check test, %	Chilled 1 week, %	Chilled 2 weeks, %	Chilled 4 weeks, 1st test, %	Chilled 4 weeks, 2nd test, %	Chilled 8 weeks, %
				Harvest of 1937					
S-74 . . .	July 4, '37	78.0	Oct. 27, '37	34.0	42.0†	62.0	53.5	—	—
			Dec. 10, '37					66.5	61.0
S-197 . . .	Aug. 14, '37	76.0	Oct. 26, '37	58.0	47.0†	66.0	66.5		
			Dec. 10, '37					74.5	75.5§
S-198 . . .	Aug. 14, '37	76.0	Oct. 26, '37	52.0	71.0†	65.0	63.5		
			Dec. 10, '37					64.0	73.0
S-199 . . .	Sept. 30, '37	54.0	Oct. 26, '37	51.5	45.0†	45.0	37.5		
			Dec. 10, '37					55.0	—
S-205 . . .	Sept. 30, '37	85.3	Oct. 28, '37	32.0	43.0†	51.0	70.0		
			Dec. 10, '37					81.0	83.0
S-229 . . .	July 17, '37	76.5	Jan. 4, '38	57.5	64.0	60.0	75.0		68.0 (2½ months)
S-249 . . .	Jan. 31, '38	61.0	Feb. 15, '38	51.5	—	—	58.7		
			April 19, '38	28.0‡				55.0	
S-250 . . .	Feb. 28, '38	72.0	Mar. 5, '38	61.5	—	—	59.5		61.5
Averages		72.4		49.7	51.0	58.1	60.5	70.1	70.3
				Harvest of 1938					
S-295 . . .	Aug. 16, '38	56.14	Aug. 31, '38	9.5	—	18.5			
			Dec. 4, '38				40.5		42.5**
			Feb. 15, '39	29.0‡	20.0	33.5‡		46.5	
S-297 . . .	Aug. 16, '38	36.97	Oct. 25, '38	33.0	34.5	39.5	32.5		
			Dec. 14, '38						24.7**
S-302 . . .	Sept. 17, '38	68.2	Oct. 24, '38	46.0	48.0	58.5§	56.5		
			Jan. 15, '39		35.5‡	54.0‡		55.0	53.0 KNO_3**
S-303 . . .	Sept. 17, '38	69.0	Oct. 24, '38	39.5	49.3	65.5	64.0		
S-606 . . .	Oct. 29, '38	58.15	Feb. 16, '39	47.5	39.0§	41.5	54.5§		
Averages		57.69		35.1	44.1	44.7	47.6		

*All tests germinated 4×50 in soil in Petri dishes. Duration of tests, 2 months, or for one month after chilling.
†Chilled 4 days.
‡Not averaged.
§Variation between quadruplicate counts more than 10.0%.
**Soaked overnight, not chilled.

material from the ground results in a low percentage of burs in the harvested material. Harvesting before burs are mature and have been weathered results in low germination when planted.

Burs which were at least partially weathered in appearance were made to germinate in the laboratory to within 10.0% of seed set or caryopsis count, either without treatment, or by soaking, or by chilling.

Burs which were immature and greenish, or mature but not weathered, gave increased germination after prolonged chilling or after warm stratification followed by cold treatment. A series of 44 such samples proved rather conclusively that the profound dormancy of this seed cannot be overcome appreciably without prolonged chilling at least for more than a month. Harvesting burs after a period of natural weathering is therefore recommended.

Optimum germination tests were made in sterilized soil in Petri dishes at a daily temperature alternation of 20°-30°, or 20°-35° C, with light, and required 6 to 8 weeks. No germination took place at or below 10° C (50° F) Dormant grains were made to germinate by puncturing the pericarp.

Of burs examined, the majority contained one or two caryopses per bur, a few contained three or four. In germination tests the majority of burs germinating produced one or two seedlings, a small percentage three or four. When diseased and healthy grains were present in the same bur, the germination of the healthy grains was in no way changed.

The presence on occasional plants and also in most seed samples of nematode galls suggests a disease widespread in Texas and of possible economic importance.

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THE ELIMINATION OF DIFFERENCES IN INVESTMENT IN THE EVALUATION OF FERTILIZER ANALYSES[1]

W. B. ANDREWS[2]

THE most desirable fertilizer analysis for the farmer to use produces the most profit per dollar invested. Fertilizer analyses tests have usually been conducted using a definite rate of each analysis fertilizer per acre. In most of the tests conducted in Mississippi, 600 pounds per acre of the different analysis fertilizers have been used. The home-mixed costs of 600 pounds of the different fertilizer analyses vary from $5.00 to $9.02.

When used at a definite rate per acre, often ferrilizers of high analysis and high cost produce the most profit per acre and the least profit per dollar invested, while fertilizers of low analysis and low cost produce the least profit per acre and the most profit per dollar invested.

If the tests had been conducted using a definite amount of money invested in each analysis instead of a definite rate per acre of each analysis fertilizer, the fertilizer which would return the farmer the most profit per dollar invested could be determined easily. Where fertilizer analysis tests have been conducted using a definite rate per acre of each analysis, it is desirable to eliminate the differences in cost before calculating the profit per dollar invested.

Where a rate of one analysis fertilizer test has been conducted in conjunction with the test of different analyses, as has been the case in Mississippi, the data on rates may be used to eliminate differences in cost of the different analyses. The purpose of this paper is to present a method for eliminating differences in investment in the evaluation of fertilizer analyses, from which the fertilizer analysis which will return the farmer the most profit for the expenditure of a definite amount of money for fertilizer may be determined.

SOURCE OF DATA

The data used for the calculations presented in this paper were obtained from Mississippi Agricultural Experiment Station Bulletin 289, 1930, "Commercial Fertilizers for Cotton, 1925–1930". Weighted averages were made of the tests conducted in each soil area of the State. The data are reported in Table 1.

METHOD OF CALCULATION

The increase in yield of seed cotton from the application of 600, 1,200, 1,800, and 2,400 pounds per acre of 4–8–4 fertilizer for each soil area was plotted on graph paper. Both "factory-mixed" and "home-mixed" costs of the fertilizer were plotted with the corresponding rate. The increase in yield in pounds of seed cotton per acre was

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TABLE 1.—*The cost of fertilizers, and increase in yield of seed cotton in Mississippi analyses and rates tests, 1925–1930.*

Rate and analysis	Cost of fertilizer		Increase over no fertilizer, pounds seed cotton per acre						
	Factory mixed	Home mixed	Lime-stone upland	Sandy loam bottom land	Flat-woods upland	Shortleaf pine upland	Longleaf pine upland	Brown loam upland	Av. of non-lime-stone upland*
Varying Potash									
600 lbs. 4–8–0	$7.21	$5.34	297	162	354	493	414	361	420
600 lbs. 4–8–2	7.59	5.80	311	357	374	549	492	475	472
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
600 lbs. 4–8–6	8.34	6.82	274	532	417	586	473	511	492
600 lbs. 4–8–8	8.72	7.31	299	587	457	567	407	498	477
Varying Phosphorus									
600 lbs. 4–4–4	7.24	5.00	329	400	325	564	387	360	425
600 lbs. 4–6–4	7.60	5.66	337	462	383	582	414	400	460
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
Varying Nitrogen									
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
600 lbs. 6–8–4	9.05	7.67	447	499	480	747	484	491	570
600 lbs. 8–8–4	10.14	9.02	533	484	576	774	539	564	630
Varying Rates of 4–8–4									
600 lbs. 4–8–4	7.97	6.32	281	477	401	561	472	577	478
1,200 lbs. 4–8–4	15.94	12.64	528	725	662	861	686	618	736
1,800 lbs. 4–8–4	23.91	18.96	654	798	748	1024	730	746	834
2,400 lbs. 4–8–4	31.88	25.28	767	848	828	1067	704	833	866
Yield without fertilizer			571	829	329	471	670	618	490

*Except brown loam.

plotted on the vertical axis; the rate of application of fertilizer and the costs per acre were plotted on the horizontal axis. Then a line of best fit was drawn for the data. The costs of the fertilizers were based on local prices of mixed fertilizers, nitrate of soda, superphosphate, and muriate of potash. The line of best fit was represented by the type of equation $Y=a+bX+cX^2$.

Where Y = increase in yield per acre, X = amount of fertilizer applied per acre, and a, b, and c are constants of the equation. The part of the curve below 600 pounds per acre of 4–8–4 fertilizer was drawn in with a french curve. The line may be drawn in free hand or by use of a french curve; the line so drawn is nearly as accurate as the calculated line of best fit.

The plotted curve represents the increase in yield for 4–8–4[3] at any rate from 0 to 2,400 pounds per acre. The curve is reliable between slightly below the 600 and 2,400 pound rates per acre, which was the part of the curves used in arriving at the calculations reported in this paper. All of the fertilizer analyses were applied at the rate of 600 pounds per acre.

The relative value of 4–8–4 and other analyses was determined by reading from the curve the amount of seed cotton which would have been produced by the same amount of money invested in 4–8–4 as was invested in 600 pounds of the analysis in question. The values so obtained were used to calculate the amount of seed cotton which would have been produced by $100.00 worth of the fertilizer applied to 12.55 acres, from which the profit per $100.00 invested was calculated using a value of three and one-half cents per pound for seed cotton.

The average increase in yield obtained from the use of different analysis fertilizers and rates of 4–8–4 in the different soil areas are reported in Table 1. The increases in yield and profits from $100.00 invested in different analysis fertilizers are reported in Tables 3 and 4, respectively.

RESULTS AND DISCUSSION

The shortleaf pine data (Fig. 1) are used to illustrate the application of the method for eliminating differences in investment in fertilizer analyses. The calculations are accumulated in Table 2. The increases in yield produced by 600 pounds per acre of the different analyses are recorded in column 4; in columns 5 and 6, the yield which would have been obtained from the application of 4–8–4 costing the same amount as 600 pounds of the different factory-mixed and home-mixed fertilizers is recorded. These yields were obtained from the curve. As an illustration, 600 pounds of factory-mixed 4–4–4 cost $7.24 and produced 564 pounds of seed cotton. From the curve, it is found that $7.24 worth of 4–8–4 produced 530 pounds of seed cotton. With $7.24 invested in factory-mixed 4–4–4 and in 4–8–4, the increase in yield was 564 and 530 pounds of seed cotton, respectively. Where equal costs are involved, differences in investment are eliminated. The application of $100.00 worth of 4–8–4 at $7.97 per acre on 12.55 acres produced 7,039 pounds of seed cotton. With $100.00 invested in 4–4–4, the increase in yield was 7,039×

[3]N, P_2O_5, and K_2O, respectively.

TABLE 2.—*Data used in the elimination of differences in investment in the evaluation of fertilizer analyses tests, shortleaf pine upland.*

Analysis	Cost of fertilizer		Increase in yield, pounds seed cotton per acre	Calculated increase in yield—same cost in 4–8–4*		Increase yield per $100.00 invested		Profit per $100.00 invested	
	Factory mixed	Home mixed		Facti	Home	Factory	Home	Factory	Home
4–8–0	$7.21	$5.34	493	530	505	6,548	7,974	$129.18	$179.09
4–8–2	7.59	5.80	549	550	533	7,026	8,413	145.91	194.46
4–8–4	7.97	6.32	561	—	—	7,039	8,168	146.37	185.88
4–8–6	8.34	6.82	586	585	594	7,051	8,058	146.79	182.03
4–8–8	8.72	7.31	567	600	615	6,652	7.530	132.82	163.55
4–4–4	7.24	5.00	564	530	484	7.491	9.518	162.19	233 13
4–6–4	7.60	5.66	582	548	527	7.476	9,020	161.66	215.70
6–8–4	9.05	7.67	747	612	635	8,592	9,609	200.72	236.32
8–8–4	10.14	9.02	774	663	707	8,217	8,942	187 60	212.97

*The increases in yield for 4–8–4 fertilizer costing the same as the different analysis fertilizers were obtained from the curves.

TABLE 3.—*Calculated increase in yield of seed cotton per $100.00 invested in cotton fertilizers applied to 12 55 acres.*

Analysis	Limestone soils		Silt and sandy loam bottom		Flatwoods uplands		Shortleaf pine upland		Longleaf pine upland		Average shortleaf pine, longleaf pine, and flatwood uplands	
	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed
4–8–0	3,997	5,324	2,126	2,558	4,662	5,866	6,548	7,974	5,400	6,553	5,572	6,735
4–8–2	4,032	5,194	4,546	5,391	4,764	5,860	7,026	8,413	6,266	7,407	6,048	7,205
4–8–4	3,526	4,392	5,985	6,901	5,031	6,048	7,039	8,168	5,922	6,775	5,997	6,976
4–8–6	3,253	3,933	6,432	7,199	4,948	5,798	7,051	8,058	5,717	6,435	5,961	6,770
4–8–8	3,423	4,041	6,862	7,716	5,249	6,115	6,652	7.530	4,801	5.365	5,598	6,326
4–4–4	4,428	6,282	5,262	6,636	4,247	5,616	7.491	9.518	5,037	6,303	5,602	7,231
4–6–4	4,353	5,759	5,883	7,023	4,854	6,080	7.476	9,020	5,261	6,317	5,894	7,131
6–8–4	4,956	5,724	5,732	6,377	5,390	6,177	8,592	9,609	5,620	6,187	6,548	7,309
8–8–4	5,339	5,972	5,038	5,642	6,000	6,686	8,217	8,942	5,889	6,351	6,747	7,300

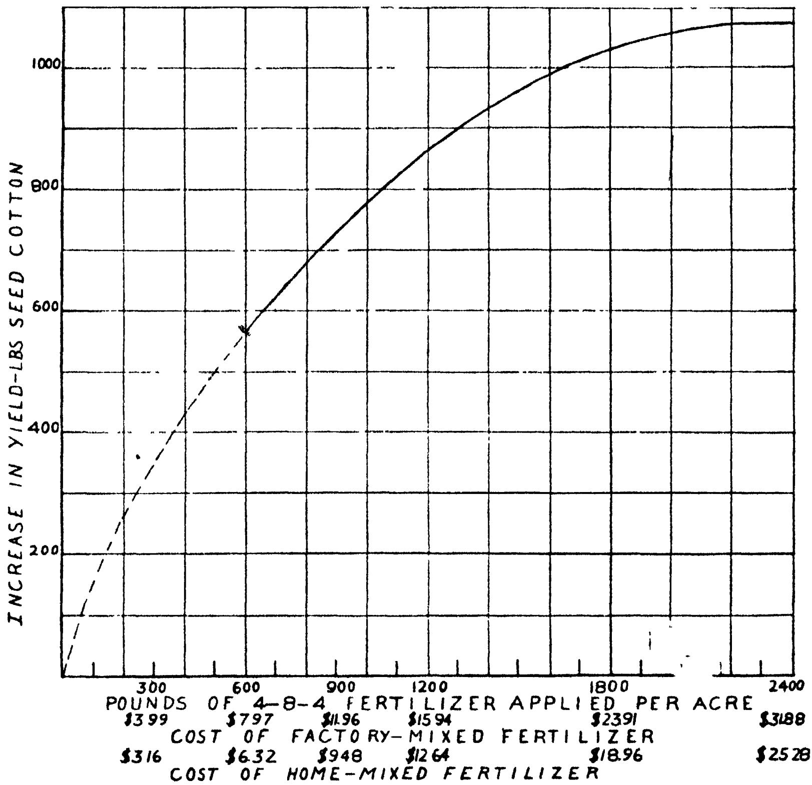

FIG. 1.—The relation of rate of application and investment in 4-8-4 fertilizer to the increase in yield of seed cotton on the shortleaf pine soils.

564÷530 or 7,491 pounds of seed cotton. The profit was determined by multiplying the pounds of seed cotton by three and one-half cents and subtracting $100.00.

In the elimination of differences in investment between factory-mixed and home-mixed fertilizers, the rate of application per acre was higher for the home-mixed fertilizer due to the fact that home-mixed fertilizers were cheaper. Consequently, the calculation for the increase in yield for $100.00 worth of home-mixed 4-8-4 was based upon the increase in yield from $7.97 worth of home-mixed fertilizer per acre applied to 12.55 acres. The increase in yield for $7.97 worth of home-mixed 4-8-4 fertilizer was obtained from the curve and multiplied by 12.55 which gives 8,168 pounds of seed cotton. The increase in yield from $5.00 worth of home-mixed 4-4-4, and 4-8-4 was 564 and 484 pounds of seed cotton per acre, respectively. The increase in yield for $100.00 worth of home-mixed 4-4-4 was found to be 8168×564÷484=9,518 pounds of seed cotton. Multiplying 9,518 pounds by the value of seed cotton (3½ cents per pound) and subtracting $100.00 gives a profit of $233.13.

TABLE 4.—*Calculated profit per $100.00 invested in cotton fertilizers applied to 12.55 acres.*

Analysis	Limestone upland		Silt and sandy loam bottom		Flatwoods		Shortleaf pine upland		Longleaf pine upland		Average shortleaf pine, longleaf pine, and flatwoods uplands	
	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed	Factory mixed	Home mixed
4-8-0	$39.90	$ 86.34	$-25.59	$-10.47	$ 63 17	$105.31	$129.18	$179.09	$ 89.00	$129.36	$ 95.02	$135.73
4-8-2	41.12	81.79	59.11	88.69	66.74	105.10	145.91	194.46	119.31	159 25	111.68	152.18
4-8-4	23.41	53.72	109.48	141.54	76.09	111.68	146.37	185.88	107.27	137.13	109.90	144.16
4-8-6	13.86	37.66	125.12	151.97	73.18	102.93	146.79	182.03	100.10	125.23	108.64	136.95
4-8-8	19.81	41.44	140.17	170.06	83.72	114.03	132.82	163.55	68.04	87.78	95.93	121.41
4-4-4	54.98	119.87	84.17	132.26	48 65	96.56	162.19	233.13	76 30	120.61	96.07	153.09
4-6-4	52.36	101.57	105.91	145.81	69.89	112.80	161.66	215.70	84.14	121.10	106.29	149.59
6-8-4	73.46	100.34	100.62	123.20	88.65	116.20	200.72	236.32	96.70	116.55	129.18	155.82
8-8-4	86.87	109.02	76.33	97.47	110.00	134.01	187.60	212.97	106.12	122.29	136.15	155.50
Best analyses	8-8-0* 6-8-4†	4-4-0* 8-8-0*	4-8-8	4-8-8	8-8-4 6-8-4†	8-8-4	6-8-4	4-4-4 6-8-4	4-8-2 4-8-4† 8-8-4	4-8-2	8-8-4 6-8-4	4-8-2 4-4-4 4-6-4 6-8-4 8-8-4

*Other data are available which show an 8-4-0 to be as profitable for these soils as an 8-8-0. Potash was omitted because it was not needed.
†Best analysis which can be bought mixed.
In the brown loam area a 4-8-4 has given the best results. $100.00 worth of home-mixed fertilizer was equal to $126.04 worth of factory-mixed fertilizer on brown loam soils.

With the differences in investment in fertilizer analyses eliminated, it is possible to point out relations between the response to analyses which do not show up with the usual interpretation. The 4-8-2 analysis was definitely more profitable than the 4-8-0 and 4-8-8, and practically as profitable as 4-8-4 and 4-8-6. Factory-mixed 4-4-4 produced a profit of $162.19 and 8-8-4 produced a profit of $187.60. Where the fertilizers were home-mixed, the 4-4-4 made a profit of $233.13 and the 8-8-4 made $212.97. $100.00 worth of 4-4-4 and 6-8-4 made profits of $162.19, and $200.72 when factory-mixed, and $233.13 and $236.32 when home-mixed, respectively. Where phosphorus varied, phosphoric acid equal to the nitrogen was as profitable or more profitable than higher ratios of phosphorus to nitrogen.

The limestone upland soils did not respond to potash, but they gave excellent responses to nitrogen. On the basis of the data presented, the best analysis with factory-mixed fertilizers was an 8-8-4, and with home-mixed fertilizers, 4-4-4 or 8-8-4. However, other data are available which show that 8-8-0 and 8-4-0 are equally profitable for these soils.

The sandy loam and silt loam bottom soils were very responsive to potash and phosphorus. The best analysis was a 4-8-8.

The longleaf pine soils were more responsive to a 4-8-2 than to any other fertilizer. It should be borne in mind that the fertilizers used in these tests were: nitrate of soda, superphosphate, and muriate of potash. When fertilizers were home-mixed, the 4-8-2 fertilizer made $22.12 more per $100.00 invested in fertilizer than did 4-8-4 and all other analyses made less profit than did 4-8-4.

The ratio of nitrogen to potash in the 4-8-2 analysis is the same as that in the 8-8-4, and practically the same as that in the 6-8-4. These soils responded to high amounts of superphosphate. The high response to superphosphate is due, partly at least, to the extremely acid condition of the soils. Under these conditions, superphosphate supplies calcium as a nutrient to the crops. On the basis of the work conducted at other places in the State, liming should reduce the superphosphate requirement of these soils and the analysis should then fall within the range of other less acid soils which give the best response to a 6-8-4 or an 8-8-4.

The average of the data for the flatwoods, shortleaf pine and longleaf pine uplands is probably a better generalization for these soils than the data for the separate areas unless lime should reduce the phosphate requirement on the strongly acid soils. When the fertilizers were factory-mixed, the 8-8-4 was slightly superior to the 6-8-4 analysis, and these analyses were superior to all others. When the fertilizers were home-mixed and $100.00 worth of fertilizers used a 4-8-2, 4-4-4, 4-6-4, 6-8-4, and 8-8-4 were almost equally profitable.

The brown loam upland data would not lend themselves to the statistical treatment, and no analysis was superior to a 4-8-4.

HOME-MIXED VERSUS FACTORY-MIXED FERTILIZERS

When fertilizers were home-mixed, 26% more fertilizer was obtained for the expenditure of a definite amount of money for 4-8-4 fertilizer than when they were bought factory-mixed. In considering

only the best factory-mixed and the best home-mixed analyses for each soil area, the expenditure of $100.00 for home-mixed fertilizer resulted in the following profits over the same amount of money invested in factory-mixed fertilizers:

Limestone upland	$33.00
Bottom land	29.89
Flatwoods upland	24.01
Shortleaf pine upland	35.60
Longleaf pine upland	39.94

The relative difference between the profit obtained with the use of different factory-mixed analyses will approach that obtained with the home-mixed analyses when the analyses of the factory-mixed fertilizers are increased (maintaining the same ratio) to 20 units of plant nutrients. The reason for this is that the cost of the fertilizing constituents is less in the higher analysis fertilizers.

SUMMARY AND CONCLUSIONS

Fertilizer analyses tests are usually conducted on the basis of a given number of pounds per acre of the different analysis fertilizers. Where the percentages of nitrogen, phosphoric acid, and potash vary, there is in reality a rates test of all three elements. Where rates vary, the operation of the law of diminishing returns may prevent the interpreter from arriving at the analysis from which the farmer will obtain the most profit for the money invested in fertilizers. A method was presented for calculating the analysis from which a farmer would obtain the most profit for a definite amount of money invested in fertilizers. The method of eliminating differences in investment is based upon the data obtained from a rates of one analysis test which is conducted in conjunction with the analysis test. The data are plotted and a curve of best fit is drawn. From the curve, the increase in yield from fertilizer equal in cost to the analysis fertilizer being compared with the plotted analysis fertilizer is obtained. With equal costs the best fertilizer may be determined and the calculations made for any convenient investment in fertilizer.

GERMINATION OF SEED OF VINE-MESQUITE, *PANICUM OBTUSUM*, AND PLAINS BRISTLE-GRASS, *SETARIA MACROSTACHYA*[1]

VIVIAN K. TOOLE[2]

VINE-MESQUITE, *Panicum obtusum*, H. B. K. and plains bristle-grass. *Setaria macrostachya*, H. B. K. are perennial grasses of the southwest; the former species having the wider distribution. *Panicum obtusum* grows in moist places and *Setaria macrostachya* grows in dry ground. Hoover (6)[3] refers to the use of *Panicum obtusum* in erosion control work. He states that seed collected from natural stands was often of low quality and did not germinate well. Since difficulty had been encountered with these 2 species in obtaining field stands from seedings and in obtaining complete germination of the viable seed in the laboratory a study was made to determine how much the poor germination was due to resistance to germination and how much was due to poor quality. The results presented are based on too few samples to be considered conclusive, but should be suggestive to future workers on the germination of these species.

Wilson (15) obtained an average germination of 2% over a 6-year period on seed of *Panicum obtusum*. He germinated the seed at 20° C to 30° alternation for a 30-day period.

Jackson (8) obtained as high as 30% germination on *Panicum obtusum* at 25° C.

Burton (2) found treatment with crude sulphuric acid beneficial for the germination of some southern grasses of the tribe *Paniceae*. Hiltner (5), Harrington (3, 4), Morinaga (9), Bryan (1), Stoddart and Wilkinson (11), and Huntamer (7), have reported on the beneficial effect of treating other grass seed with concentrated sulphuric acid. Toole (12), (13), (14) found approximately 71% by volume (approximately 80% by weight) sulfuric acid beneficial for some grass seed.

MATERIAL AND METHODS

The seed used in these studies was furnished through the courtesy of M. M. Hoover of the Soil Conservation Service. The historical data on the samples is given in Table 1. The seed as received was separated by an air blast blower and sieves into two groups, *viz.*, (a) empty and immature florets, and (b) heavy, filled florets or mature seed. The approximate purity, that is, the percent of mature seed, of the samples of *Panicum obtusum* as received varied from 20 to 98%. The samples were stored in paper bags in the laboratory for the duration of the experiment. Only the mature seed was used in this study. "Seed" as used in this paper includes the caryopsis, the chartaceous-indurate lemma and palea, and the herbaceous glumes.

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[1]Contribution from the Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. This work was conducted in the former Division of Seed Investigations, Bureau of Plant Industry. Received for publication March 25, 1940.

[2]Junior Botanist.

[3]Figures in parenthesis refer to "Literature Cited", p. 512.

The seed was pretreated and germinated according to the methods described in the paper "The germination of seed of *Oryzopsis hymenoides*" (14). Germination results summarized in Tables 2 to 8 are in all cases mean values, based on duplicate tests of 100 seeds each. In Table 5, half percents have been raised to the next higher percentage. Values for tests of significance of differences have been calculated by the analysis of variance method as adapted by Snedecor (10).

TABLE 1.—*Descriptive data on all samples of seed.*

Sample No.	Date of collection	Place of collection	Date received in laboratory	Notes by collector	Approximate purity of sample %
		Panicum obtusum			
761229	———	Texas	July 17, '36	———	—
766605	———	———	Nov. 3, '37	———	—
766902	Crop of 1937	Yukon, Okla.	Dec. 17, '37	———	20
766905	Oct. 21, '37	Wildorado, Tex.	Dec. 17, '37	Obtained from drainway bottom along railroad	24
766907	Oct. 31, '36	Mountainair, N. M.	Dec. 17, '37	Collected with hand strippers at elevation of approximately 6,000 feet	33
767285	Nov. 26, '37	Cowans Ranch, McNeal, Ariz.	Jan. 10, '38		98
		Setaria macrostachya			
761228	———	Nursery, Tucson, Ariz.	July 17, '36		—
767279	Aug. '37	Nursery, Tucson, Ariz.	Jan. 10, '38		76

VINE-MESQUITE

GERMINATION TEMPERATURE

Four samples of *Panicum obtusum* were germinated in soil in Petri dishes at constant temperatures of 15°, 20°, 25°, 30°, and 35° C and at alternating temperatures of 15° to 25°, 20° to 30° with light,[4] 10° to 35°, 35° to 10°, room temperature to 35°, 20° to 35°, 20° to 40° and 25° to 40°. The results are given in Table 2. The mean germination of the four samples shows that alternating temperatures

[4]Definite light exposure at 30° in glass enclosed chamber in north window. Other temperature conditions, except room temperature to 35°, did not have definite light exposure but light was not excluded.

are superior to constant temperatures for the germination of seed of *Panicum obtusum*.

The seed germinated approximately the same at a wide range of alternating temperatures that include the lower temperature for the longer period of the alternation. The 35° to 10° alternation was significantly poorer and the room temperature to 35° alternation was significantly better than the other alternating temperatures tried. The room temperature to 35° alternation did not produce complete germination of the viable seed in 28 days in all cases. With sample 766902 germination appeared to be completed at this temperature in 28 days but with sample 761229 apparently complete germination was not obtained until 70 days. Sample 766905 and 766907 still showed 8 and 10% sound seed respectively at the end of 130 days at alternation of room temperature to 35°. Sample 766905 germinated higher at alternation 20° to 35° than at alternation room temperature to 35° and showed apparently complete germination of the viable seed in 63 days at the former alternation. The mean results of another series of tests given in Table 4 show no significant difference between the alternation room temperature to 25° and 20° to 35° germination temperatures.

POTASSIUM NITRATE

Tests were conducted at eight alternating temperatures with the use of 0.2% solution of potassium nitrate and with water to determine the effect of nitrate on the germination of the seed. The mean results in Table 3 illustrate the beneficial effect from the use of potassium

TABLE 2.—*The 28-day germination in soil in Petri dishes of seed of Panicum obtusum at various temperatures, average of duplicate 100-seed tests.**

Temperature of germination chamber, °C	Percentage germination shown by different samples on indicated dates				
	761229, Aug. 14, 1936	766902, Jan. 13, 1938	766905, Jan. 13, 1938	766907, Jan. 13, 1938	Mean
15°	7.0	19.0	11.0	12.0	12.25
20°	22.0	41.5	22.5	16.5	25.63
25°	31.0	49.0	30.5	9.0	29.88
30°	22.5	53.5	25.0	13.5	28.63
35°	19.5	40.0	20.0	7.5	21.75
15° to 25°	30.0	51.5	47.5	30.5	39.88
20° to 30° with light	30.0	52.5	50.5	32.5	41.38
10° to 35°	36.0	50.5	43.5	36.5	41.63
35° to 10°	27.5	50.0	47.0	15.5	35.00
Room to 35°	50.5 (2)†	72.0 (0)	45.5 (28)	37.5 (13)	51.38
20° to 35°	25.5	64.0	63.0 (8)	13.5	41.50
20° to 40°	23.0	58.5	45.0	34.5	40.25
25° to 40°	26.0	58.5	41.0	30.5	39.00
Mean	26.96	50.81	37.85	22.27	34.47

*According to t test, differences required for significance are: Between means of two observations, 21.30; between means of eight observations, 5.33, 26 observations, 2.76%.

†Figures in parenthesis after percentage of germination show approximate precentage of apparently sound seed remaining at the end of 28 days.

nitrate. It was observed that the papery glumes are readily infected by a black fungus that retards root development and that this was more apparent when the seed was germinated on moistened toweling than when germinated on soil. The combined effect of potassium nitrate and an alternating temperature did not bring about complete germination of all the viable seed, especially of sample 767285. The mean results for both temperatures in Table 4 also show an increased germination from the use of potassium nitrate for untreated seed but not for treated seed.

PRECHILLING

Three samples were prechilled for 14, 28, and 56 days at 3°, 10°, and 15° C before germination at alternation of room temperature to 35°. The results were somewhat inconsistent but there was an indication that prechilling at 3° for 28 days was beneficial on one sample (766907).

TREATMENT WITH SULFURIC ACID

Other writers have shown that grass seeds restricted in their germination by the seed or fruit coat could be made to germinate by altering the coat by means of sulfuric acid treatment. The seed of *Panicum obtusum* was treated with approximately 71% by volume (approximately 80% by weight) sulfuric acid for 0, 30, 60, 90, and 120 minutes. The germination results at alternation of room temperature to 35° C and at 20° to 35° with water and with potassium nitrate show a benefit of acid treatment (Table 4). The means for the two temperatures indicate a highly significant increase of germination for each successively longer treatment up to 90 minutes These differences are due largely to the results with sample 766907. Sample 761229 and 766605 did not show any marked effect of acid treatment on final germination, but the rate of germination of these samples was increased by treatment (Table 5).

Germination results in soil with two additional samples not given in the table showed a similar benefit from acid treatment. With these samples, removal of the papery glumes by light rubbing with emery paper had no effect on germination.

CHANGE IN RESPONSE WITH AGE

One sample first tested in 1936 and five samples originally tested in January and February 1938 were again tested under the same conditions in January and February 1939. A parallel germination after treatment of the seed with approximately 71% by volume sulfuric acid for 90 minutes was made on each sample at the time of the second test. The results with potassium nitrate are given in Table 5. Sample 761229 had fallen in viability in the period of more than 3 years between the two tests, but the rate of germination of this old seed was hastened by acid treatment. The seed of sample 766902 became more resistant to germination during storage for a year, but it would not appear that viability had fallen as shown by the germination after acid treatment. The response of seed of samples 766605 and 766907

TABLE 3.—*Germination in 28 days of seed of Panicum obtusum at indicated temperatures, February 2, 1938, average of duplicate 100-seed tests.**

Sample No.	Percentage germination at indicated temperatures							
	15°–25°	20°–30°	10°–35°	35°–10°	Room–35°	20°–35°	20°–40°	25°–40°
				Potassium Nitrate				
766605	42.5	40.0	46.5	50.0	51.0	50.0	49.0	56.0
767285	9.5	14.0	13 5	17.0	26.0	12.5	13.5	21.5
Mean	26.0	27.0	30.0	33.5	38.5	31.25	31.25	38.75
				Water				
766605	21.0	26.5	10.0	19.0	28.5	36.5	26.5	28.0
767285	0.0	6.5	1.0	3.5	4.0	7.5	2.0	4.5
Mean	10.5	16.5	5.5	11.25	16.25	22.0	14.25	16.25

*According to *t* test, differences required for significance are: Between means of two observations 17 70, four observations 7 12%.

TABLE 4.—*Germination in 21 days of seed of Panicum obtusum at two temperatures after indicated treatments, February 8, 1939, average of duplicate 100-seed test.**

Sample No.	Approximate age of seed, years	Percentage germinated at indicated temperatures, °C											
		Room to 35°, germinated after indicated acid treatment						20 to 35°, germinated after indicated acid treatment					
		0	30	60	90	120	Mean	0	30	60	90	120	Mean
		Potassium Nitrate											
761229	4	19.0	23.5	14.5	26.5	20.0	20.7	10.5	22.0	17.0	17.5	14.0	16.20
766605	—	46.5	41.5	47.0	56.0	51.0	48.4	39.0	47.5	49.5	55.0	60.0	50.20
766907	2 1/3	42.0	52.5	79.0	83.0	77.5	66.8	34 0	55.5	67.0	79.5	78.5	62.90
Mean		35.83	39.16	46.83	55.16	49.5	45.30	27.83	41.66	44.5	50.66	50.83	43.10
		Water											
761229		20.0	26.0	19.5	23.0	21.5	22 0	21.5	21.0	17.5	21.5	22.5	20.80
766605		39 0	45.0	58.5	62.5	59.5	52.9	38.5	48.0	51.5	61.5	60.0	51.90
766907		25.5	40.5	60.0	64.0	71.5	52.3	21.5	42.0	52 0	58.0	55.0	45.70
Mean		28.16	37.16	46.0	49.83	50.83	42.40	27.16	37.0	40.33	47.0	45.83	39.46
Mean	Means	31.99	38.16	46.41	52.49	50.16	43.85	27.49	39.33	42.41	48.83	48.33	41.28
Mean for 2 temperatures:													
Potassium nitrate		31.83	40.41	45.66	52.91	50.16	44.20						
Water		27.66	37.08	43.16	48.41	48.33	40.93						
Potassium nitrate and water		29.74	38.74	44.41	50.71	49.24	42.56						

*According to t test, differences required for significance are: Between means of two observations, 19 77. four observations, 7.95, six observations, 5.91; ten observations, 4.31; twelve observations; 3.89; 24 observations, 2.67%.

TABLE 5.—*Change in response of Panicum obtusum to the alternating temperature, room temperature to 35° C, with age of seed, average of duplicate 100-seed test.*

Sample No.	Date tested	Approximate age when tested	Treatment	Percentage germination after		
				7 days	14 days	21 to 28 days (final)
761229	Aug. 14, '36	1 year	None	46	50	51
	Feb. 8, '39	4 years	None	4	18	19
	Feb 8, '39	4 years	Sulfuric acid 90 minutes	23	27	27
766902	Jan. 12, '38	3 months	None	11	71	72
	Jan. 17, '39	15 months	None	5	48	50
	Jan. 17, '39	15 months	Sulfuric acid 90 minutes	65	69	69
766605	Feb. 2, '38	———	None	32	49	51
	Feb 8, '39	———	None	36	46	47
	Feb 8, '39	———	90 minutes	55	56	56
766907	Jan. 13, '38	15 months	None	8	34	38
	Feb. 8, '39	28 months	None	8	33	45
	Feb 8, '39	28 months	90 minutes	60	81	83
766905	Jan. 13, '38	3 months	None	13	35	46
	Jan. 16, '39	15 months	None	32	53	54
	Jan. 16, '39	15 months	90 minutes	59	62	62
767285	Feb. 2, '38	3 months	None	2	21	26
	Feb 8, '39	15 months	None	15	43	47
	Feb. 8, '39	15 months	90 minutes	44	66	68

did not change between the two tests, but the rate and amount of germination at the second test was increased by acid treatment. The germination of seed of samples 766905 and 767285 was appreciably better at the second test but was still further improved both in rate and amount by acid treatment. The results presented do not show a consistent improvement of germination as the seed ages, but whatever the age of the seed, the rate of germination was increased by acid treatment.

PLAINS BRISTLE-GRASS

The results from tests with seed of *Setaria macrostachya* serve only as suggestions for the optimum germination condition for this seed since only two samples were available. The results from tests conducted at various constant and alternating temperatures indicate that alternating temperatures of 35° to 10° C and 10° to 35° are better than the other temperatures tried (Table 6).

The mean germination of seed prechilled at 3° or at 10° is significantly better than the mean germination of seed not prechilled (Table 7). Seed from sample 767279 was also prechilled but was not included in the table as 22% was the highest result obtained.

Seeds were pretreated for 0, 15, 30, 45, and 60 minutes with approximately 71% by volume (80% by weight) sulfuric acid and germinated at alternation 20° to 30° with light with the use of potassium nitrate and water. The mean results show 15 and 30

TABLE 6.—*The germination in 42 days in soil in Petri dishes of Setaria macrostachya at various temperatures, average of duplicate 100-seed tests.**

Sample No.	Date of germination test	Percentage germination after 42 days at indicated temperatures, °C										
		20°	25°	30°	35°	20° to 30° with light	20°–35°	15°–25°	10°–35°	35°–10°	20°–40°	25°–40°
761228...	Aug. 14, 1936	57.5	43.5	6.0	3.0	53.0	47.5	48.0	65.5	67.0	47.0	56.5
767279...	Feb. 4, 1938	6.0	5.0	3.0	8.0	10.5	6.5	5.0	7.5	15.5	2.0	9.5
Mean....		31.75	24.25	4.5	5.5	31.75	27.0	26.5	36.5	41.25	24.5	33.0

*According to *t* test, differences required for significance are: Between means of two observations, 14.25, between four observations, 5.73%.

minutes to be the best treatments and germination was increased by the use of potassium nitrate after these treatments (Table 8).

TABLE 7.—*The germination in 66 days in soil in Petri dishes of seed of Setaria macrostachya after prechilled treatments, sample 761228, August 14, 1936, average of duplicate 100-seed tests.**

Germination temperature, °C	Percentage germination after prechilling at indicated temperature for 2 to 4 weeks				
	3° C		10° C		Check No. prechilling
	2 weeks	4 weeks	2 weeks	4 weeks	
20° to 30° with light	60 0	64.5	60.5	62.0	54
20° to 35° .	61.5		59.5		50
20° to 40° .	61.0		61 0		48.5
Mean . .	60.83		60.33		50.83

*According to t test, differences required for significance are: Between means of two observations, 19 81%, six observations, 5 92%

TABLE 8.—*The germination in 28 days of seed of Setaria macrostachya at 20° to 30° with the influence of potassium nitrate after various pretreatments with approximately 71% sulfuric acid, March 6, 1939, average of duplicate 100-seed tests.**

Sample No.	Treatment of substrata	Percentage germination after indicated acid treatment					Mean
		0 minutes	15 minutes	30 minutes	45 minutes	60 minutes	
761228	Potassium nitrate	37.5	59.0	60.0	40.5	46.0	48.6
	Water	32.0	46.5	43 5	38.0	35.5	39.1
Mean		34 75	52.75	51.75	39 25	40.75	43.85
767279	Potassium nitrate	21.0	44.5	44.5	41.0	23.5	34.9
	Water	26.5	40.5	46.0	42.0	32.0	37.4
Mean		23.75	42.5	45.25	41.5	27.75	36.15
Mean	Potassium nitrate	29.25	51.75	52.25	40.75	34.75	41.75
Mean	Water	29.25	43.5	44.75	40.0	33.75	38.25
Mean	Means	29.25	47.62	48.5	40.37	34.25	40.00

*According to t test, differences required for significance are: Between means of two observations, 15.04; between four observations, 6.04; eight observations, 3.74; sixteen observations, 2.52%.

DISCUSSION

It appears that much of the failure to obtain field stands from seed of *Panicum obtusum* and *Setaria marcostachya* may be due to unfilled or immature florets. However, resistance of the seed coat offers a problem in the germination of the seed as shown by the improved

germination of both species from acid treated mature caryopses. Complete germination of the viable seed was obtained on seed of *Panicum obtusum* after acid treatment. The condition of the non-germinating seed of *Setaria macrostachya* was not determined. The endosperm remained sound in both species. The embryo of *Panicum obtusum* either germinated or decayed. The embryo of *Setaria macrostachya* discolored but did not become soft. It is probable that many of the non-germinating seeds of this species were dormant and that the proper condition for complete germination was not found.

SUMMARY

The alternating temperatures, room temperature to 35° C, or 20° to 35°, were significantly better for the germination of the seed of *Panicum obtusum* than the other alternating or constant temperatures tried. Germination was increased by a dilute solution of potassium nitrate. Pretreatment of the seed with approximately 71% sulfuric acid for 90 minutes overcame the resistance of the seed to germination. There was no consistent improvement of germination with age, but whatever the age of the seed, the rate of germination was increased by acid treatment.

The seed of *Setaria macrostachya* germinated best at alternating temperature of 10° to 35° C or 35° to 10°. The seed was benefitted by prechilling or by pretreating with approximately 71% sulfuric acid for 15 to 30 minutes. Potassium nitrate improved germination.

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SIGNIFICANCE OF ADSORPTION, OR SURFACE FIXATION, OF PHOSPHORUS BY SOME SOILS OF THE PRAIRIE GROUP[1]

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PHOSPHORUS fixation by soils has been studied for many years. Much has been learned of the processes whereby phosphorus may be removed from solution by soils to which it is applied. The literature concerning the subject is voluminous but even a cursory perusal of the various publications reveals that there is much yet to be learned concerning at least some of the fixation processes.

Without attempting to review the extensive literature, it shall suffice here to point out that several recent contributors have proposed that, within certain ranges of reaction, at least, phosphorus is adsorptively[3] fixed on the surfaces of clay particles. Representative papers are those of Roszmann (16),[4] Bradfield, Scarseth and Steele (1), Scarseth (17), Mattson (9), Pugh and du Toit (13), and Ravikovitsch (14). Since the alumino-silicate complex of most soils is negatively charged several theories have been offered to explain adsorption of phosphorus. Adsorption through one or more free aluminum valences has been offered as an explanation. Displacement of OH^- groups from an alumino-silicate structure is another explanation, and replacement of 2 Si by a PAl complex has also been proposed. Schofield (18) found that montmorillonitic, kaolinitic, and halloysitic clays have nearly constant electrical charges from pH 6.0 downward. He also found that some other clays (not mineralogically identified) did not behave as the above mentioned types. At low pH values, these clays, he believes, carry positive charges; his results indicated that they adsorb Cl^- from HCl solution. Murphy (11) showed that ground kaolinite possesses high fixing capacity for phosphorus, and that kaolinitic clay is also characterized by high phosphorus fixing capacity. Mattson and Karlsson (10) propose two types of binding by soil colloid particles, in addition to chemical precipitation. In the one type, designated "colloid bound," the phosphorus is presumed to enter into the micellar structure. In the other type, called "saloid bound," the phosphorus, probably as $H_2PO_4^-$, forms an outer circle, or a part of an outer circle, of electrically charged (negative) ions about the micelle, balancing positive charges

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[2]Associate Professor of Soils. That portion of the work reported in this paper which deals with attempts to bring about an equivalent exchange of phosphate by oxalate was done in the laboratories of the Soils Department, University of Wisconsin, where the writer spent the summer of 1938 on sabbatical leave. Gratitude is hereby expressed to the Soils Department for the facilities made available and to Professor E. Truog for counsel and advice.

[3]Throughout this paper fixation of phosphorus at particle surfaces in a replaceable form is referred to as adsorption, while absorption implies some form of chemical precipitation such as precipitation as phosphates of Ca, Mg, Fe, Al, or possibly as certain complex phospho-silicates.

[4]Figures in parenthesis refer to "Literature Cited", p. 525.

in the cationic layer. Toth (21) believed that the reaction involved in displacement of phosphate by silicate, for example, is probably not similar to that of equivalent cation exchange.

REPLACEMENT OF PHOSPHATE BY OXALATE

The first experiments undertaken in the work reported here involved attempts at replacement of adsorbed or surface fixed phosphate from the surfaces of soil particles. Many difficulties were encountered. The two anions most prominently mentioned as effective in replacement of phosphate are the silicate and the hydroxyl ions. Neither lends itself well to determination of the amount adsorbed by the soil. Citrate, oxalate and humate were listed by Bradfield, Scarseth and Steele (1) as effectively reducing the retention of phosphate by clays, the order of effectiveness being the order in which they are named. Steele (19) attempted to compare the oxalate retained by clay with the amount of phosphate which the clay was prevented from fixing when suspended in a phosphate-oxalate solution in comparison with a pure phosphate solution. The results indicated considerably more oxalate retained than phosphorus released and he believed that oxidation of some of the oxalate by the soil was responsible for the discrepancies.

For the study of replacement of phosphate by oxalate, surface soil samples from cultivated fields in various locations in eastern Kansas were employed. In order to eliminate some of the sources of fixation of phosphorus, the organic matter and free iron oxides were removed from the samples by the method outlined by Truog, *et al.* (22). The samples were then subjected to the phosphorus fixation procedure described by Heck (8), that is, each soil sample was treated with a phosphate solution in a flask and the solution boiled vigorously until nearly dry, after which the evaporation was completed more slowly at a lower temperature. A 1-gram soil sample treated as just indicated was dispersed in a flask by shaking vigorously with 25 mls of distilled water, brought onto a filter paper in a small Buchner funnel and subjected to filtration with suction. The first portion of filtrate, if cloudy, was refiltered.

The soil sample was then leached on the funnel with distilled water until the leachate gave no test for phosphorus. The water leachate was then removed and the soil sample further leached with 50 mls of N/50 ammonium oxalate. This salt was chosen because its solution in water is practically neutral in reaction. The 50 mls were applied to the soil in 10 portions of 5 mls each. This was followed by further leaching of the soil sample with distilled water until the leachate gave no test for oxalate. The amount of oxalate retained by the soil was then determined by titrating the leachate with $KMnO_4$ and comparing the titration with that for an equivalent amount of the original oxalate solution. Phosphorus was determined colorimetrically in the oxalate leachate and also in the distilled water leachate.

Colorimetric determination of phosphorus by the improved Denigès method of Truog and Meyer (23) was attempted in the oxalate leachate after titration with N/50 $KMnO_4$. It was found that the determination could not be carried out satisfactorily under these

conditions. Neither could phosphorus be determined successfully in the presence of much unoxidized oxalate. However, when a portion of the oxalate filtrate was titrated with permanganate and the remaining portion likewise titrated to within about 0.3 ml of the end-point, the latter could then be used for the determination of phosphorus. The blue color of the phosphorus determination must be developed, however, at a pH value of 1.0 or below.

The soils, after treatment to remove free iron oxides, and after the phosphorus fixation treatment, had their base-adsorbing capacity partially satisfied by Na^+ and partially by K^+, since NaCl solutions were used in the washings of the first operation, and KH_2PO_4 solution was used in the phosphorus fixation treatment.

Samples of bentonite and of nontronite were included with the soil samples for comparison. These samples were prepared by saturating them with Na^+ by leaching with NaCl solution. After washing free of chlorides, the samples were digested over night at 80°–90° C with 1.5% Na_2CO_3 solution. The Na_2CO_3 solution was then filtered off and the samples washed free of carbonates. This treatment served to remove free silica and aluminum oxides from the samples.

The results of the replacement studies with several soils and with the nontronite and bentonite samples are given in Table 1.

TABLE 1.- *Phosphorus extracted from soils, first by water, than by ammonium oxalate, and oxalate retained.**

Sample description	Phosphorus leached out by water, p.p.m.	Additional phosphorus extracted by $(NH_4)_2C_2O_4$		Fixed phosphorus: not removed by		$(NH_4)_2C_2O_4$ retained by soil, M.E.†	pH of sample after phosphorus fixation
		P.p.m.	M E.†	Water, p.p.m.	Water and $(NH_4)_2C_2O_4$, p.p.m.		
Bentonite	271	0.0	0.0	129	129	0.0	——
Nontronite	242	0.0	0 0	158	158	0.0	——
Soil No. 1	158	8.4	0.083	142	134	0.7	5.06
Soil No. 2	148	6.0	0.06	152	146	1.4	5.34
Soil No. 3	140	7.2	0.07	160	153	0.0	5.89
Soil No. 4	147	6.0	0.06	153	147	1.4	5.42
Soil No. 5	168	7.2	0.07	132	125	0.7	5.00
Soil No. 6	176	7.8	0.075	124	116	1.2	6.09
Soil No. 7	152	7.2	0.07	148	141	0.8	5.63
Soil No. 8	168	2.4	0.023	132	130	0.8	6.20
Soil No. 9	192	5.8	0.056	108	102	1.2	6.13
Soil No. 10	184	3.6	0.035	116	112	0.0	6.13

*The free R_2O_3 of the soils had been removed, followed by addition of 400 p.p.m. of P in solution as KH_2PO_4, and evaporation.
†Milligram equivalents per 100 grams of air-dry sample.

The data indicate no equivalent replacement of phosphate by oxalate. The results for the soil samples generally indicate more oxalate retained than phosphorus released but there are two exceptions. From approximately one-third to one-half of the phosphorus used in the fixation treatment was recovered when the soil samples

were leached with water. Very little of the remaining one-half to two-thirds of the added phosphorus was extracted by leaching the soil samples with the oxalate. Hence, it would not appear that more than an extremely small portion of the phosphorus with which the samples were treated was fixed in a replaceable form, at least in so far as replacement by the oxalate ion is concerned.

In bentonite and nontronite, no phosphorus was replaced and no oxalate was retained by the sample. It will be noted that about two-thirds of the added phosphorus was extracted in the water leachings. Although the pH values of these samples after phosphorus fixation were not determined, it is probable they approximated the values for the soil samples.

In some additional work with bentonite and nontronite, it was found that samples similarly treated with phosphate yielded 355 p.p.m. and 327 p.p.m. of phosphorus, respectively, when extracted by buffered 0.002 N H_2SO_4. Thus, the buffered H_2SO_4 removed 84 p.p.m. and 85 p.p.m., respectively, more than the oxalate, and 45 p.p.m. and 73 p.p.m., respectively, were fixed in such form as not to be extracted, even by the buffered acid.

It is of interest to note that the bentonite and nontronite each fixed considerably less phosphorus in a form not soluble in water than did the soil samples. This suggests the presence of some other products of weathering in the soil which fix phosphorus besides base exchange material and free iron oxides.

EFFECT OF REMOVAL OF FREE OXIDES OF FE AND AL ON PHOSPHORUS FIXATION

It appeared desirable to determine the effect of the removal of the free oxides of iron and aluminum on phosphorus fixing capacity for a group of soils representative of the types used in the various experiments reported in this paper.

In the various papers dealing with phosphorus adsorption the influence of the pH value at which fixation occurs is stressed. It appears that the pH range 5.0 to 6.0 has been found to be a range in which such fixation is said to occur. Such being the case, soils were chosen for this work whose pH values, before treatment, fell in the range 5.0 to 6.0.

Because of the difficulty of controlling the pH value of the system in the fixation procedure of Heck (8), in all succeeding experiments the soil samples were treated with a H_3PO_4 solution so adjusted with NaOH as to have a pH value in the range 5 to 6 after being shaken for 30 minutes with the soil sample. Less phosphorus is fixed by soil samples thus treated than with the boiling and evaporation of the Heck procedure. Four phosphate solutions were prepared, containing 19, 38, 57, and 95 p.p.m. of phosphorus, respectively. For each soil sample, a phosphate solution was chosen in accordance with the fixing capacity of the soil, a solution of high concentration being used for a soil with high fixing capacity and vice versa. Ten grams of soil were shaken with 50 mls of the phosphate solution on a mechanical shaker after which the suspensions were filtered, the phosphorus in the fil-

trate determined, and the phosphorus fixed calculated as the difference between that of the original solution and that of the filtrate.

Soil samples so selected representing the surface 7 inches of soil of cultivated fields, were subjected to removal of free iron oxides. Phosphorus fixation by these samples and by a duplicate set of samples from which the oxides had not been removed was then determined. The results are presented in Table 2.

TABLE 2.—*Phosphorus fixation in pH range 5.0 to 6.0 by soils before and after removal of free oxides of iron and aluminum.*

Soil type	Phosphorus fixation by original soil, p.p.m.	Phosphorus fixation after removal of free oxides, p.p.m.	Decrease of phosphorus fixation due to removal of free oxides	
			P.p.m.	%
Shelby silt loam.....	117.5	52.5	65.0	55.3
Lancaster loam. . .	52.4	9.9	42.5	81.1
Idana silt loam.. .	137.5	110.0	27.5	20.0
Lancaster silt loam ..	52.4	7.4	45.0	85.8
Gerald silty clay loam	122.5	22.5	100.0	81.6
Summit silty clay loam	59.9	27.4	32.5	54.4
Albion loam	44.9	2.5	42.4	94.4
Marshall silt loam .	127.4	87.4	40.0	31.4
Labette silt loam . .	178.6	48.6	130.0	72.7
Wabash silt loam....	147.7	102.4	45.3	30.6

The 10 soils listed varied rather widely in the percentage decrease in phosphorus fixation, the range being 20% to 94%. Only 3 of the 10 showed less than 50% decreases and 5 showed decreases of more than 70%. The data must not be taken too literally, however. Organic matter was removed by oxidation with H_2O_2 as the first step in the iron removal procedure and the phosphorus thus liberated was undoubtedly partially fixed by the mineral particles. The effect of this would be to decrease further fixation by the soil sample. On the other hand, the phosphorus extracted in the iron removal treatment was not determined, and this might tend to increase the fixation capacity as compared to the original soil. How these two effects compare in magnitude is not known. It can be said, however, that while other forms of fixation account for a portion of the phosphorus-fixing capacity of these soils, fixation by Fe and Al oxides apparently accounts for a large part of the fixing capacity, even in the pH range 5.0 to 6.0.

EFFECT OF DILUTE ACID EXTRACTION OF THE SOIL ON PHOSPHORUS-FIXING CAPACITY

Romine and Metzger (15) recently presented results indicating that extraction of a soil with buffered 0.002 N H_2SO_4 solution reduced its phosphorus fixing capacity. Fixation in the experiments reported in that paper was not studied under controlled pH conditions.

Two objectives were set up for additional work on the effect of dilute acid extraction on phosphorus-fixing capacity of the soil.

First, it seemed desirable to determine whether such extraction results in a disruption of the crystal structure of the particles which might account for the decrease in phosphorus fixing capacity. Second, it was desired to determine the effect of extraction on fixing capacity under conditions such that fixation should take place in the pH range 5.0 to 6.0, both before and after the extraction with the buffered acid. For this purpose soil samples were selected whose initial pH values fell in the range 5.0 to 6.0.

In order to determine whether or not extraction disrupts the crystal structure of the exchange particles, base exchange capacity was determined before and after extraction with buffered 0.002 N H_2SO_4. It was assumed that any appreciable change in crystal structure should manifest itself in a change of base exchange capacity. The results of this study with 12 samples from virgin soil profiles indicated that if change of base exchange capacity can be accepted as a criterion of crystal structure disruption, then it must be concluded that crystal structure was practically unaffected by extraction of the soil with the dilute acid. Since this has been demonstrated with other dilute acid extractants the data are not presented here.

In determining reduction of phosphorus fixing capacity resulting from extraction of the soil by dilute acid, the samples were shaken one-half hour with the extracting solution, centrifuged, the extract poured off and the sample then shaken one-half hour with a H_3PO_4 solution of appropriate concentration as explained on a preceeding page. Fixing capacity was also determined for the original soil. The results are given in Table 3. In this table the so-called "apparent fixing capacity" is a strictly arbitrary value and is obtained by adding the available phosphorus (that extracted by buffered 0 002 N H_2SO_4) to the phosphorus fixed by the original, or unextracted, soil. The soil samples were all taken from virgin soil profiles except the Nuckolls silt loam which came from an eroded, cultivated field

The data of Table 3 indicate significant, and often large, reductions in phosphorus fixation resulting from the extraction of the soil with dilute acid. On the basis of the amount of phosphorus fixed by the original soil, the reductions ranged from about 12% to 75%. On the basis of "apparent fixing capacity" the range was approximately 13% to 78%. The greatest percentage reductions occurred with samples from the A horizons, generally, while the smallest reductions occurred with C horizon samples. This again indicates the presence of products of soil weathering in surface soils which influence phosphorus fixation markedly. The results of this experiment indicate that the order of magnitude of the reductions in fixation due to dilute acid extraction is not likely to be greatly different when fixation takes place in the pH range 5.0 to 6.0 than when this range is considerably lower, as was probably the case in the work reported by Romine and Metzger (15).

INFLUENCE OF THE NATURE OF THE EXCHANGEABLE CATIONS ON PHOSPHORUS FIXATION

Phosphorus fixing capacity of soil is somewhat influenced by the nature of the exchangeable cations as shown by Perkins, King and

TABLE 3.—*Effect of extraction of the soil with buffered 0.002 N H_2SO_4 on phosphorus fixation in the pH range 5.0 to 6.0.*

Soil type, horizon, and depth, inches	Phosphorus fixed by original soil, p.p.m.	Available phosphorus by the Truog method, p.p.m.	"Apparent fixing capacity", p.p.m.	Phosphorus fixed after extraction, p.p.m.	Reduction from original fixing capacity		Reduction from "apparent fixing capacity"	
					P.p.m.	%	P.p.m.	%
Cherokee silt loam A_0, 0–4	36.2	25.6	61.8	17.3	18.9	52.2	44.5	72.0
Cherokee silt loam A_1, 4–12	60.0	8.0	68.0	14.8	45.2	75.3	53.2	78.2
Cherokee silt loam B_1, 20–23	263.3	6.0	269.3	173.6	89.7	34.1	95.7	35.5
Cherokee silt loam B_2, 23–28	258.9	4.0	262.9	183.6	75.3	29.1	79.3	30.2
Nuckolls very fine sandy loam A_1, 3–9	102.5	22.4	124.9	37.4	65.1	63.5	87.5	70.0
Nuckolls very fine sandy loam A_2, 9–17	206.4	12.0	218.4	108.6	97.8	47.3	109.8	50.3
Nuckolls very fine sandy loam B, 17–27	213.9	10.0	223.9	113.6	100.3	46.9	110.3	49.3
Idana silt loam A_1, 5–15	80.0	16.0	96.0	37.4	42.6	53.2	58.6	61.0
Idana silt loam A_2, 15–19	107.5	19.2	126.5	62.4	45.1	41.9	64.3	50.8
Nuckolls silt loam A, 0–6	115.0	10.8	125.8	62.4	52.6	45.7	63.4	50.4
Nuckolls silt loam B, 6–16	216.4	9.6	226.0	143.6	72.8	33.6	82.4	36.5
Neosho silt loam A_0, 0–2	30.0	18.4	48.4	17.3	12.7	42.3	31.1	64.2
Neosho silt loam A_1, 2–7	36.2	6.0	42.2	22.3	13.9	38.4	19.9	47.1
Neosho silt loam A_2, 7–14	77.5	6.8	84.3	60.0	17.5	22.6	24.3	28.8
Neosho silt loam B, 14+	236.4	11.2	247.6	148.6	87.8	37.1	99.0	40.0
Labette silt loam A_0, 0–2	87.5	27.2	114.7	57.4	30.1	34.4	57.3	49.9
Labette silt loam A_1, 2–8	117.5	28.0	145.5	72.4	45.1	38.4	73.1	50.2
Labette silt loam A_2, 8–16	135.0	22.4	157.4	92.4	42.6	31.5	65.0	48.1
Labette silt loam B_1, 16–22	226.4	20.8	247.2	183.6	42.8	18.9	43.6	17.6
Labette silt loam B_2, 22–28	253.9	7.2	261.1	213.6	40.3	15.9	47.5	18.2
Labette silt loam C, 28+	411.5	6.4	417.9	361.0	50.5	12.3	56.9	13.6
Summit silt loam A_1, 0–7	66.2	12.0	78.2	34.8	31.4	47.4	43.4	55.5
Summit silt loam A_2, 7–9	140.0	6.0	146.0	97.4	42.6	30.4	48.6	33.3
Bates silt loam A_1, 0–6	73.7	8.4	82.1	34.8	38.9	52.8	47.3	57.6
Bates silt loam A_2, 6–8	140.0	5.2	145.2	97.4	42.6	30.4	47.8	32.9
Bates silt loam C, 29+	425.3	3.2	428.5	366.0	59.3	13.9	62.5	14.6

Benne (12), and others. It was therefore thought possible that replacement by the monovalent cations, H^+ and NH_4^+, in the extracting solution, of the divalent cations in the exchange material might account for much of the reduction in fixing capacity.

The soils used in obtaining the data in Table 3 had their base exchange capacities satisfied by calcium to the extent of at least 40% to 65% and exchangeable potassium is known to be relatively abundant in these soils. Accordingly, a group of samples from these same soils were leached with KCl solution, and another group was leached with $MgCl_2$ solution until the leachates gave no test for calcium. They were then further leached with 80% alcohol until the leachates gave no test for chlorides The samples were then air-dried and phosphorus fixation determined, again adjusting the pH value of the phosphorus solution so that the suspension of soil in the phosphorus solution had a pH value in the range 5.0 to 6.0. The values thus obtained in comparison with the values for the original soil are presented in Table 4.

The replacement of the naturally occurring cations by K, in one instance, and Mg, in another, produced some surprising results. It was thought that probably replacement by K would lower the fixing capacity of the soil samples. This proved to be true for the upper part of nearly every profile, but when the lower part of the A horizon or the upper part of the B horizon was reached the effect was reversed. The writer has no adequate explanation for the increased fixation in the lower profile samples, unless it could be that the treatment with the potassium salt served to activate some of the iron and aluminum or other agents of fixation in these lower horizons. It will be recalled that treatment with the buffered acid reduced fixation in all horizons. Substitution of Mg increased phosphorus fixation with most samples. It did not do so uniformly, however, and the exceptions are A horizon samples, at or near the surface. The Nuckolls silt loam samples as explained previously were taken from an eroded, cultivated field, hence, the A horizon of this soil corresponded to the lower part of the A horizon of a virgin profile and showed increased fixation by the surface layer of soil.

The decrease of phosphorus fixation in the surface horizons resulting from the substitution of either K or Mg may be associated with the very high organic matter content of such samples. Doughty (4) has shown that soil organic matter has a low phosphorus fixing capacity and it is therefore difficult from this standpoint to see why the substitution of Mg, particularly, should lower the fixing capacity of such horizons. Decrease in fixation due to substitution of either K or Mg for Ca may be explained, however, on the basis of the greater solubility of the phosphorus compounds of K and Mg than those of Ca. The increase of fixation in lower horizons admits of no such simple explanation. It is interesting to note that when K markedly increased fixation, Mg did likewise. Also, the largest increases in fixation due to K and Mg occurred with the soil samples having the largest fixing capacities.

The divergent effects produced by substitution of these ions, particularly K, in the various horizons indicate that factors other than

adsorption must account for at least a very large part of the total fixing capacity of the soil. This is in agreement with the indications obtained from the results of the other experiments reported in this paper.

DISCUSSION

deVries and Hetterschij (24) have shown for a number of soils that there "was some parallelism" between the amounts of phosphorus extracted by lactic and citric acid solutions of different strengths and the combined quantities of Fe and Al removed. Romine and Metzger (15) presented data indicating a relationship between the reduction of the phosphorus fixing capacity of some Kansas soils due to extraction with dilute acid, and the quantity of R_2O_3 removed by the acid extraction. The correlation coefficient obtained from these data was $r = .497$. (Significant correlation coefficients at the 5% and 1% levels were .312 and .405, respectively). In unpublished studies by the author a negative correlation between available phosphorus of unfertilized soil as determined by the Truog method and increase in wheat yield due to phosphorus fertilization was established and the coefficient was $r = -.617$. (Significant correlation coefficients at the 5% and 1% levels were $-.482$ and $-.606$, respectively). These studies involved, along with others, the soils listed in Table 2. In view of these two correlations, and since the phosphorus fixing capacity is lowered by the same extraction which removes the available phosphorus, it seems possible that wheat grown on these soils, unless fertilized, is dependent to a large extent upon phosphorus combined with easily extractable sesquioxides.

One of the anions which has been proposed as being capable of replacement by phosphate, and which in turn may liberate phosphorus by replacement, is silicate. This relationship has been used to explain the oft-observed favorable influence of sodium silicate applications on crops grown on phosphorus deficient soils. The evidence thus obtained that phosphate is adsorbed and may be replaced by silicate is not entirely convincing. For example, in the results reported by Toth (21) the effects of calcium and magnesium silicates on the growth and phosphorus absorption of various crops showed fairly similar results when rock phosphate was the source of phosphorus as when phosphorus was supplied as superphosphate. Since phosphorus in rock phosphate is relatively only very slightly fixed by the soil while the phosphorus in superphosphate is strongly fixed, the replacement of phosphate by silicate may not be the correct explanation of the beneficial effect of silicates in these experiments. Gile and Smith (7) have shown that silica gel shaken with rock phosphate in water suspension produced a marked increase in water soluble phosphorus. Also Gaarder (6) showed that silica gel increased the amount of phosphorus in solution in the presence of Al, Ca and other elements which form relatively stable compounds with phosphorus. Perhaps, therefore, additions of silicate salts to the soil may bring about increased solubility of native soil phosphorus without a replacement of adsorbed phosphate by the silicate anion.

Ford (5) demonstrated by X-ray methods that when phosphates were fixed by Goethite and other minerals a new crystal structure

TABLE 4.—*Effect of the replacement of the naturally occurring exchangeable cations by K^+ and Mg^{++} on the fixation of phosphorus in the pH range 5.0 to 6.0.*

Soil type, horizon, and depth, inches	Phosphorus fixed by original soil, p.p.m.	Phosphorus fixed by K-soil, p.p.m.	Change in phosphorus fixation due to K, p.p.m.	Phosphorus fixed by Mg-soil, p.p.m.	Change in phosphorus fixation due to Mg, p.p.m.
Cherokee silt loam:					
A_0, 0–4	36	2	−34	12	−24
A_1, 4–12	60	26	−34	40	−20
B_1, 20–23	263	308	+45	352	+89
B_2, 23–28	259	324	+65	368	+109
Nuckolls very fine sandy loam:					
A_1, 3–9	102	88	−14	136	+34
A_2, 9–17	206	188	−18	240	+34
B, 17–27	214	204	−10	272	+58
Idana silt loam:					
A_1, 5–15	80	80	0	116	+36
A_2, 15–19	107	124	+17	148	+41
Nuckolls silt loam:					
A, 0–6	115	136	+21	160	+45
B, 6–16	216	202	−14	308	+92
Neosho silt loam:					
A_0, 0–2	30	0	−30	8	−22
A_1, 2–7	36	14	−22	36	0
A_2, 7–14	77	104	+27	116	+39
B, 14+	236	308	+72	308	+72

Labette silt loam:					
A_0, 0–2	87	64	−23	100	+13
A_1, 2–8	117	104	−13	140	+23
A_2, 8–16	135	104	−31	156	+21
B_1, 16–22	226	260	+34	292	+66
C, 28+	411	605	+194	596	+185
Summit silt loam:					
A_1, 0–7	66	38	−28	64	−2
A_2, 7–9	140	148	+8	168	+28
Bates silt loam:					
A_1, 0–6	74	42	−32	64	−10
A_2, 6–8	140	164	+24	172	+32
C, 29+	425	557	+132	548	+123

was indicated. Stout (20) reported recently that kaolinite possesses much higher phosphorus fixing capacity than bentonite because of the larger quantities of hydroxol ions available for exchange in the former than in the latter. He was able to change the crystal structure of kaolinite by phosphating it, as indicated by X-ray studies, but reports that he restored the original structure by leaching the kaolinite with an alkaline solution (pH 9.0) and washing with dilute HCl (pH 3.0).

Dean (3) extracted Rothamsted soils with N/4 NaOH and followed this by extraction with N/2 H_2SO_4. He found that half or more of the total phosphorus was not removed by these treatments. This non-extracted portion was not increased by long-continued fertilizer applications. Hence, it appears that a goodly portion of the phosphorus in these soils was neither replaceable by OH^- ions nor extractable with dilute acid.

It is not the purpose of the author to attempt to prove or disprove the theory of phosphorus adsorption by clay particles. However, it appears evident from results presented here and cited from other sources that the phosphorus fixation problem is quite different where the unfractionated soil in its natural condition is dealt with than where one works with a purified clay fraction, or a still more homogenous clay mineral.

Davis (2) studied phosphorus fixation intensively and apparently concluded, at least tentatively, that in acid soils the fixation of phosphorus can be accounted for largely by absorption and that adsorption must play a minor role It appears to be rather generally conceded that fixation in alkaline soils is largely accounted for by precipitation in combination with divalent bases.

SUMMARY

Phosphorus fixation has been studied with surface soil samples from cultivated fields and with samples from the various horizons of virgin soil profiles.

Samples from which the free oxides of iron and aluminum had been removed were treated with KH_2PO_4 solution and the water soluble phosphate leached out. The samples were then leached with ammonium oxalate solution in an attempt to demonstrate an equivalent replacement of phosphate by oxalate. Only very small amounts of phosphate could be removed by the oxalate and there were no indications of an equivalent replacement. Samples of bentonite and nontronite showed similar results.

Removal of free oxides of iron and aluminum reduced the fixing capacity (in the pH range 5.0 to 6.0) of 10 soil samples by amounts varying from 20% to 94%.

Extraction of soil samples with buffered 0.002 N H_2SO_4 reduced the fixing capacity of the soil (measured in the pH range 5.0 to 6.0) by from 12% to 78%. It was shown that this treatment scarcely altered the base exchange capacity of the samples and therefore it was assumed that the reduction of phosphorus fixing capacity could not be attributed to disruption of the crystal structure of the base exchange particles by the dilute acid treatment.

Replacement of the naturally occurring exchangeable cations (predominantly Ca^{++}) from the soil particles by K^+ lowered the phosphorus fixing capacity of most samples from the A horizons of virgin soils. Samples from the lower A horizons and the B and C horizons showed increased fixing capacity after such treatment. The same was true when Mg^{++} was substituted for the naturally occurring cations except that fewer samples showed reduced fixing capacity.

The effects of the various treatments on phosphorus fixing capacity suggest the presence and activity in unfractionated and unaltered soils of accumulated products of soil forming processes which play a dominant role in phosphorus fixation.

The conclusion is drawn that, for acid soils under field conditions absorption, or chemical precipitation, may account very largely for phosphorus fixation and that adsorption, a surface phenomenon, is probably of small practical significance.

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THE GROWTH HABITS AND CHEMICAL COMPOSITION OF BROMEGRASS, *BROMUS INERMIS* LEYSS, AS AFFECTED BY DIFFERENT ENVIRONMENTAL CONDITIONS[1]

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PIPER (6)[3] and other investigators have reported that bromegrass, *Bromus inermis* Leyss, if allowed to grow undisturbed for two or three years, becomes "sod-bound." A marked decrease in the percentage of fertile shoots produced is associated with this condition. This characteristic has been observed in other grasses and as yet no definite explanation has been offered. The investigations of Kraus and Kraybill (5) with the tomato, *Lycopersicon esculentum*, indicate that fruitfulness is associated with a balance between the nitrates and carbohydrates in the above-ground parts. In order to obtain information as to the relation of these constituents to the habits of growth of bromegrass, studies of two types were undertaken: First, the effects of nitrogen fertilizer, shade, shade combined with nitrogen fertilizer, and the associated growth of alfalfa with bromegrass upon its habits of growth and chemical composition; and second, the effects of length of day upon such qualities and characteristics of bromegrass.

EFFECT OF NITROGEN FERTILIZER, SHADE, SHADE COMBINED WITH NITROGEN FERTILIZER, AND MIXTURE WITH ALFALFA UPON THE GROWTH HABITS AND CHEMICAL COMPOSITION OF BROMEGRASS

PLAN OF EXPERIMENT

Bromegrass seed of a commercial strain from Saskatchewan was seeded on plots 10×10 feet on September 1, 1936, and on August 28, 1937. The plots were arranged in the following order: Nitrogen fertilized, check, mixture with alfalfa, and shaded. Since the alfalfa in the 1936 seeding failed to survive, a plot both shaded and fertilized with nitrogen was substituted.

Shading was provided by bleached sheeting over wooden frames constructed to allow 6 inches at the bottom and an opening on the north side for ventilation. The frames were placed on the plots of each seeding on March 24, 1938. The light intensity under the frames ranged from 300 to 800 foot candles as compared to normal sunlight of 4,000 to 10,500 foot candles on July 7, 1938.

Records were obtained on the date of appearance of leaves, increase in height of shoots, elongation of internodes, appearance of fertile and sterile[4] shoots, ap-

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[3]Figures in parenthesis refer to "Literature Cited", p. 537.

[4]Sterile shoot same as vegetative shoot (absence of inflorescence).

pearance and growth of rhizomes, and the yield of plant parts. The yields were determined from square-foot areas taken to a depth of 6 inches.

Duplicate determinations of total nitrogen, free reducing sugars, sucrose, and easily hydrolyzed carbohydrates were made in 50-gram samples of hay, stubble, and roots; and in 10-gram samples, of rhizomes from plots in the 1936 seeding.

Extraction of the samples.—The samples were extracted with 80% alcohol for 12 hours in large Soxhlet extractors.

Total nitrogen.—Determinations for nitrogen in the extract and dry residue were made by the official Kjeldahl method.

Free reducing sugars.—Fifty cc of alcohol extract were placed in a 100-cc volumetric flask and the alcohol driven off on the steam bath. The sample was cleared with lead acetate and potassium oxalate, then made up to volume and filtered. A 25-cc aliquot was used for the determination of free reducing sugars.

Total sugars.—Two drops of invertase (1% solution of Wallensteins' red label) were added to a 25-cc aliquot of the cleared extract and allowed to remain for 2 hours. After inversion, determinations were made for free reducing sugars. To determine the percentage *sucrose*, the percentage free reducing sugars was subtracted from the percentage total sugars.

Easily hydrolyzed carbohydrates.—A 2-gram sample of the dry residue was ground fine and hydrolyzed with 2.5% HCl for 2.5 hours in a receiving flask. The free reducing sugars were determined on a 10-cc aliquot of the filtrate.

GROWTH HABIT STUDY

The rate of appearance of leaves was changed very little by different environmental treatments. Nitrogen fertilizer increased the rate of appearance slightly over that of the check plot. Blackman and Templeman (1) obtained similar results on rate of leaf production in *Agrostis tenuis* and *Festuca rubra* as affected by nitrogen fertilizer. Shading of bromegrass plants reduced the rate of appearance of leaves in the fall, but had little effect in the spring and summer as compared with the check plants.

Rhizomes appeared in the first two weeks of May following the previous fall seeding. The number of rhizomes per plant appeared to be dependent in part upon the density of the stand. Very few rhizomes were observed in dense stands. Dexter (2) reported similar results on the number of quack grass rhizomes as affected by the density of stand.

Data on square-foot harvests from the two sets of plots at three different dates are presented in Tables 1 and 2. The nitrogen-fertilized plot produced the highest number of fertile shoots in all instances. Shading of the plants definitely decreased the number of fertile shoots produced. The percentage fertile shoots recorded on June 30, 1938, was 50 in the nitrogen-fertilized plot as compared to 35 in the check plot, 18 in the shaded nitrogen-fertilized plot, and 10 in the shaded plot.

The total number of shoots produced was greatest in the nitrogen-fertilized plot; however, the difference between the nitrogen-fertilized plot and check plot was slight in the 1936 seeding. Shading decreased the total number of shoots per unit area.

The number of rhizomes produced per square-foot area was greatest in the check plot. Both nitrogen fertilizer and shade tended to decrease the number of rhizomes produced.

The height of fertile shoots was increased by shade and nitrogen fertilizer. Shade seemed to be the most effective of the two treatments. The plants both shaded and fertilized with nitrogen fertilizer attained the greatest height at the time of maturity. The number of elongated internodes on fertile shoots was greatest on the shaded plants, and they were more uniform in length than on the unshaded plants.

TABLE 1.—*Shoots and rhizomes from square-foot areas in each plot.*

Treatment	Average number per square foot				Average height of fertile shoots, inches
	Fertile shoots	Sterile shoots	Total shoots	Rhizomes	
Two Square-foot Harvests per Plot, June 25, 1938, in 1937 Seeding					
Check plot	17.5	130.5	148.0	24.0	13.3
N-fertilized plot*	54.5	127.5	182.0	22.5	35.6
Shaded plot	0.0	103.5	103.5	7.0	——
Alfalfa-bromegrass plot	10.0	122.0	132.0	8.0	28.1
Four Square-foot Harvests per Plot, July 5, 1938, in 1936 Seeding					
Check plot	25.5	110.0	135.0	57.5	28.2
N-fertilized plot*	46.3	84.7	131.0	38.5	38.6
Shaded plot	16.0	86.5	102.0	19.5	45.4
Shaded N-fertilized plot*	19.0	86.5	105.5	15.5	49.0
Four Square-foot Harvests per Plot, Aug. 2, 1938, in 1937 Seeding					
Check plot	7.0	139.0	146.0	29.5	24.5
N-fertilized plot*	33.5	173.2	206.7	15.2	41.3
Shaded plot	0.0	71.5	71.5	7.2	——
Alfalfa-bromegrass plot	8.2	103.5	111.7	10.2	37.2

*Ammonium sulfate at the rate of 150 pounds per acre was applied on March 24 and July 2, 1938. The 1937 seeding was fertilized at the same rate on September 20, 1937.

The yield of hay on the fertilized plot was about four times as great as the check plot in the 1937 seeding, as shown in Table 2. Shading of the plots decreased the amount of dry weight as compared with the check plots. The yield of alfalfa and bromegrass hay together approached the yield of hay obtained on the nitrogen-fertilized plot.

In all instances the check plot produced the greatest dry weight of bromegrass rhizomes. The production of bromegrass rhizomes was retarded by nitrogen fertilizer. This response to nitrogen fertilizer was observed by Willard and McClure (8) in Kentucky bluegrass. Dexter (2) obtained similar results with high nitrogen fertilization in the production of rhizomes in quack grass. Both shade and alfalfa mixture decreased the yield of bromegrass rhizomes.

TABLE 2.—*Yield in pounds dry weight per acre calculated from square-foot harvests made in 1938.*

Treatment	Yield in pounds per acre				
	Hay	Stubble	Roots	Rhizomes	Total
	June 25 Harvest, 1937 Seeding				
Check	1,300	1,550	1,370	80	4,300
N-fertilized*	5,890	2,590	1,540	50	10,070
Shaded	1,180	440	350	5	1,975
Alfalfa-bromegrass	1,100	750	760	20	2,630
alfalfa	4,080	710	1,100		5,890
Total alfalfa-grass mixture	5,180	1,460	1,860	20	8,520
	July 5 Harvest, 1936 Seeding				
Check	2,170	3,280	3,400	340	9,190
N-fertilized*	4,930	2,950	2,940	240	11,060
Shaded	2,580	1,290	1,580	70	5,520
Shaded N-fertilized*	2,970	1,850	1,410	70	6,300
	August 2 Harvest, 1937 Seeding				
Check	1,730	1,030	2,570	90	5,420
N-fertilized*	6,930	2,110	2,370	60	11,470
Shaded	1,460	360	280	15	2,115
Alfalfa-bromegrass	1,710	550	920	30	3,210
alfalfa	2,820	390	1,050		4,260
Total alfalfa-grass mixture	4,530	940	1,970	30	7,470

*Ammonium sulfate at the rate of 150 pounds per acre was applied on March 24 and July 2, 1938. The 1937 seeding was fertilized at the same rate on September 20, 1937.

The yield of roots appeared to be stimulated by nitrogen fertilizer in the early stages of growth. After the plants were well established, the nitrogen fertilizer tended to retard the growth of the roots as indicated by the data obtained on July 5 and on August 2. Since the samples were taken to a depth of only 6 inches, the data are not complete; however, examination of the soil to a depth of 12 inches indicated that a small percentage of the roots extended to a greater depth than 6 inches.

The nitrogen-fertilized plants produced the greatest total dry weight of plant parts. This was followed in succession by the check plot, shaded nitrogen-fertilized plot, and the shaded plot in the 1936 seeding. In the 1937 seeding, the bromegrass in the alfalfa mixture yielded more than the shaded plot.

CHEMICAL ANALYSES

The duplicate analyses of plant parts were in relatively close agreement. Analyses of plant parts harvested June 29–30, 1938, from the 1936 seeding, are presented in Table 3. The percentage free reducing sugars was approximately the same in the hay samples for each treatment. The stubble showed an increase in free reducing sugars in the nitrogen-fertilized plants over that of the check plants. This effect

was even more pronounced in the rhizomes. In the analysis of total plants, the nitrogen-fertilized plants contained the highest percentage of free reducing sugars.

The percentage sucrose present in the hay was highest in the two fertilized plots. The percentage in the underground parts appeared to be decreased by shading of the plants. Nitrogen fertilizer gave the highest percentage of sucrose in the total plant.

There was no definite trend shown in the percentage of easily hydrolyzed carbohydrates with different treatments. Total carbohydrates determined were higher in the unshaded plants than in the

TABLE 3.—*Chemical analyses of plant parts harvested June 29–30, 1938, from the 1936 seeding.*

Material	Treatment			
	Check %	N-fertilized %	Shaded %	Shaded N-fertilized %
Hay:				
Relative proportion of parts	23.6	44.5	46.8	47.2
Free reducing sugars	1.6	2.2	2.0	2.1
Sucrose	1.7	2.0	0.5	2.1
Easily hydrolyzed carbohydrates	26.2	29.1	24.3	22.5
Total carbohydrates determined	29.5	33.3	26.8	26.7
Total nitrogen	1.7	1.4	1.9	2.3
Stubble:				
Relative proportion of parts	35.7	26.7	23.4	29.3
Free reducing sugars	1.0	1.4	1.0	1.0
Sucrose	1.4	0.9	0.8	0.8
Easily hydrolyzed carbohydrates	31.4	31.3	27.2	26.8
Total carbohydrates determined	33.8	33.6	29.0	28.6
Total nitrogen	0.8	0.9	1.2	1.8
Roots:				
Relative proportion of parts	37.0	26.6	28.6	22.4
Free reducing sugars	0.8	0.7	0.5	0.4
Sucrose	1.2	1.2	0.5	0.5
Easily hydrolyzed carbohydrates	28.2	26.8	28.5	28.2
Total carbohydrates determined	30.2	28.7	29.5	29.1
Total nitrogen	0.9	1.0	1.0	1.8
Rhizomes:				
Relative proportion of parts	3.7	2.2	1.2	1.1
Free reducing sugars	2.0	3.1	1.3	1.6
Sucrose	2.0	2.3	0.1	1.3
Easily hydrolyzed carbohydrates	30.5	29.4	26.6	25.6
Total carbohydrates determined	34.5	34.8	28.0	28.5
Total nitrogen	1.0	1.2	1.7	2.6
Total plant:				
Relative proportion of parts	100.00	100.00	100.00	100.00
Free reducing sugars	1.17	1.67	1.22	1.39
Sucrose	1.37	1.55	0.50	1.31
Easily hydrolyzed carbohydrates	28.90	28.90	26.20	25.00
Total carbohydrates determined	31.44	32.12	27.92	27.70
Total nitrogen	1.04	1.13	1.52	2.03

shaded plants; however, there was little difference between the two shaded plots or between the two unshaded plots.

The percentage of nitrogen was highest in the shaded nitrogen-fertilized plot and lowest in the check plot. Little difference was shown in the percentage of nitrogen between the two shaded plots or between the two unshaded plots. The ratio of carbohydrates determined to total nitrogen in bromegrass— check plot, 28.2:1; nitrogen-fertilized plot, 27.5:1; shaded plot, 18.8:1; and shaded nitrogen-fertilized plot, 13 6:1—gives a more contrasting difference than a comparison of the percentage within the plant.

There appears to be little correlation between the chemical analyses and shoot growth. The total number of fertile shoots produced in the nitrogen-fertilized plot was about twice as great as in the check plot, and yet the analyses are similar and the ratios are approximately the same. If the yields of plant parts harvested on July 5, 1938, from the 1936 seeding, are used to determine the yield of carbohydrate fractions and total nitrogen per acre, a more definite relationship is shown. The amount of carbohydrate determined for the whole plant in the check plot was 2,890 pounds per acre as compared with 3,550 in the nitrogen-fertilized plot, 1,540 in the shaded plot, and 1,750 in the shaded nitrogen-fertilized plot. The amounts of nitrogen were about the same in the two unfertilized plots and the same in the two fertilized plots. With high amounts of nitrogen and normal light intensity, there is an increase in the production of shoots in number and dry weight This is accompanied by a decrease in the number and weight of rhizomes which serve as a source of organic reserves for the stimulated top growth. With the added stimulus of nitrogen fertilizer, there is sufficient food material to cause the initiation and growth of more fertile shoots. Conversely, when the fertility level is low, the excess carbohydrates produced are stored or used in the production of more rhizomes. The hypothesis is suggested that, if the latter condition exists for a few years, a dense sod is formed and some type of special treatment is needed to stimulate the top growth.

Shading of the bromegrass plants had somewhat the same effect as the nitrogen fertilizer upon the general growth habit. The carbohydrate reserves in the rhizomes and the carbohydrates produced were used in the production of top growth. This resulted in a decrease in the number and weight of rhizomes.

These results suggest that under normal conditions of growth of bromegrass, there is a tendency toward excess storage in the underground parts. This condition may be altered by stimulating the top growth with nitrogen fertilizer in the spring. This effect tends to be carried over throughout the growing season.

EFFECT OF LENGTH OF DAY UPON GROWTH HABITS AND CHEMICAL COMPOSITION OF BROMEGRASS

PLAN OF EXPERIMENT

Three experiments were conducted with duplicate plots of bromegrass under three different lengths of day. The experiments extended from (a) May 17 to July 9, 1937, (b) September 20 to November 27, 1937, and (c) April 2 to July 28,

1938. Experiments (a) and (c) consisted of plants transplanted to rows one foot apart and spaced 6 inches apart in the rows. The plants in experiment (b) were grown from seed in rows 8 inches apart and thinned on September 20 to approximately 4 inches apart. The dark boxes and lights were used alike in all experiments.

One set of plots was covered each day from 4:30 p.m. to 8:00 a.m. with ventilated boxes, thus giving the plants 8.5 hours daily illumination. A second set of plots was grown under natural illumination. The third set of plots, located about 400 feet from the other plots, was artificially illuminated so that it received 18 hours daily illumination. At the surface of the soil the artificial illumination ranged from 65 to 80 foot candles throughout the plot area.

As far as possible in all three experiments, records were obtained on all plants as to the number of fertile shoots, number of sterile shoots, length of longest shoot, and number and length of rhizomes. Yields of plant parts were determined on 30 plants from each length of day in 1938. Analyses for carbohydrate fractions and nitrogen were made on samples of hay, stubble, roots, and rhizomes collected on July 28, 1938, from each length of day. The methods of analysis are described on page 528.

GROWTH OF SHOOTS AND RHIZOMES

Plants grown under short days produced a rosette type of growth and the shoots developed in a decumbent position. The plants grown under normal and long days developed in an upright position, the long-day plants attaining a greater height than the normal-day plants. Records obtained on the growth habits of shoots on these plants at the end of each experiment are presented in Table 4.

No differences in the number of fertile shoots per plant were obtained in the plots in 1937, since plants were transplanted in the spring after inflorescences were initiated. In 1938 the plants were

TABLE 4.—*Average number and length of shoots per plant as affected by different lengths of day.*

Date and length of day	Fertile shoots per plant, No.	Total shoots per plant, No.	Height of tallest sterile shoots per plant, in.*	Height of tallest fertile shoots per plant, in.
July 9, 1937:				
Short days, 8.5 hours	1.0	20.9	†	12.2
Normal days, 15.0 hours	1.0	17.0	†	20.3
Long days, 18.0 hours	0.8	10.9	†	25.8
November 24, 1937:				
Short days, 8.5 hours	None	7.6	5.3	
Normal days, 11.0 hours	None	7.1	5.1	
Long days, 18.0 hours	None	3.1	14.2	
July 28, 1938:				
Short days, 8.5 hours	1.2	24.7	7.4	15.3
Normal days, 15.0 hours	3.7	21.7	14.6	22.8
Long days, 18.0 hours	1.4	16.7	30.7	25.3

*Measurements made from base of shoot to uppermost ligule.
†Not determined.

transplanted early and the greatest number of fertile shoots developed under normal days. These data indicate that bromegrass would fall into the class of indeterminate plants described by Garner (4). None of the shoots on plants grown in the fall of 1937 showed initiation of inflorescences. If the plants had been subjected to different lengths of day throughout their early growth in fall and spring, the reaction might be somewhat different with respect to development of inflorescences.

The total number of shoots per plant became greater with a decrease in length of day. With an increase in length of day, the height of the shoots became greater. When plants were grown under long days for a period after maturity, the sterile shoots attained a greater height than the fertile shoots.

Data on the growth of rhizomes on plants from the three dates of experiments are shown in Table 5. The data indicate that length of day has a definite effect on the production of rhizomes, the greatest number being produced under normal days in the spring and summer.

TABLE 5.—*Average number and length of rhizomes as affected by different lengths of day.*

Date and length of day	Primary rhizomes per plant, No.	Branch rhizomes per plant, No.	Total rhizomes per plant, No.	Length of longest rhizomes per plant, in.
July 9, 1937:				
Short day, 8.5 hours	6.1	1.9	8.0	2.7
Normal day, 15.0 hours	11.7	4.6	16.3	3.8
Long day, 18.0 hours	8.5	7.0	15.5	4.0
November 24, 1937:				
Short day, 8.5 hours	None	None	0	0
Normal day, 11.0 hours	None	None	0	0
Long day, 18.0 hours	2.2	None	2.2	2.3
July 28, 1938:				
Short day, 8.5 hours	3.4	0.6	4.0	*
Normal day, 15.0 hours	9.7	2.9	12.6	*
Long day, 18.0 hours	6.2	2.8	9.0	*

*Not determined.

The rhizomes on plants grown under long days attained a greater length and appeared to be larger in diameter than those on plants from the other two lengths of day. Conversely, it was observed that the plants grown under short days produced more above-ground shoots from rhizomes than the normal or long-day plants.

The indications from all experiments seem to be conclusive that length of day is an important factor in the production of rhizomes. Evans and Watkins (3) found that rhizome production on bluegrass was strongly affected by length of day. The greatest number developed on *Poa compressa* in the early spring and late fall, or under short days; and on *Poa pratensis* in the late spring and early summer, or under relatively long days.

The yield per acre of plant parts of bromegrass was determined on 30 plants from each length of day in 1938. The data are shown in Table 6. Long days tended to increase the proportion of hay and rhizomes. The yield of stubble and roots under long days was not appreciably increased over that of normal-day plants. In similar experiments with *Dactylis glomerata* and *Phleum pratense*, Tinker (7) obtained less dry weight of tops of both grasses under short days than under long days.

TABLE 6.—*Yield per acre of plant parts on July 28, 1938, as affected by length of day.*

Material	Yield per acre, lbs.		
	Short day	Normal day	Long day
Hay	1,780	2,520	4,780
Stubble	870	1,380	1,310
Roots	500	910	910
Rhizomes	70	230	400
Total	3,220	5,040	7,400

CHEMICAL[1] ANALYSES

Analyses of plant parts harvested on July 28, 1938, are given in Table 7. The percentage of free reducing sugars increased in all plant parts with an increase in length of day. This is shown rather definitely in the analysis of the total plant. The percentages of sucrose are erratic, showing no definite trend with change in length of day. Long days tended to increase the percentage of easily hydrolyzed carbohydrates in the hay and stubble, with a corresponding decrease in roots and rhizomes. The total carbohydrates determined in hay, stubble, and the total plant were highest under long days; the underground parts showed little variation with change in length of day.

The total percentage nitrogen showed a decline with increase in length of day in all plant parts with the exception of roots. It is apparent that with a decided change in total dry weight, the percentage of nitrogen would vary accordingly. The ratio of carbohydrates to total nitrogen—short day, 6.3:1; normal day, 12.5:1; and long day, 15.4:1—is not in accord with that obtained in the first part of this study. The ratio for the normal-day plants is much lower than that for the check plants. The probable explanation for this difference is found in the arrangement of plants, the length-of-day plants being grown individually without competition.

The actual amounts of nitrogen per acre as determined from the yields in Table 6 are relatively the same—short day, 70 pounds; normal day, 60 pounds; and long day, 80 pounds. The total carbohydrates determined were—short day, 410 pounds; normal day, 740 pounds; and long day, 1,380 pounds. No definite correlations are apparent between these data and the growth habits observed. It appears, however, that length of day is important for the maximum

TABLE 7.—*Chemical analyses of plant parts harvested July 28, 193?, from length-of-day plots.*

Material	Length of day, %		
	Short day, 8.5 hours	Normal day, 15 hours	Long day, 18 hours
Hay:			
Relative proportion of parts	55.1	49.6	64.5
Free reducing sugars	1.0	1.4	2.7
Sucrose	1.9	1.2	1.3
Easily hydrolized carbohydrates	15.9	22.8	23.8
Total carbohydrates determined	18.8	25.4	27.8
Total nitrogen	5.2	3.3	2.4
Stubble:			
Relative proportion of parts	26.5	27.2	18.0
Free reducing sugars	1.8	1.6	2.8
Sucrose	0.9	1.6	1.4
Easily hydrolyzed carbohydrates	25.5	29.4	28.4
Total carbohydrates determined	28.2	32.6	32.6
Total nitrogen	2.4	1.4	0.9
Roots			
Relative proportion of parts	16.1	18.1	12.1
Free reducing sugars	0.8	0.8	1.5
Sucrose	0.4	*	1.6
Easily hydrolyzed carbohydrates	29.2	27.9	26.9
Total carbohydrates determined	30.4	28.7	30.0
Total nitrogen	1.1	1.1	1.1
Rhizomes:			
Relative proportion of parts	2.3	5.1	5.4
Free reducing sugars	1.8	4.0	4.5
Sucrose	1.0	1.2	2.2
Easily hydrolyzed carbohydrates	34.8	34.1	30.7
Total carbohydrates determined	37.6	39.3	37.4
Total nitrogen	1.1	1.5	1.4
Total plant:			
Relative proportion of parts	100.0	100.0	100.0
Free reducing sugars	1.1	1.4	2.7
Sucrose	1.3	1.1	1.3
Easily hydrolyzed carbohydrates	21.0	26.0	25.4
Total carbohydrates determined	23.4	28.5	29.4
Total nitrogen	3.7	2.3	1.8

*Not sufficient extract for analysis.

production of fertile shoots and rhizomes. After the required length of day is exceeded, the additional carbohydrates produced are used in the growth of the vegetative parts in size and length.

SUMMARY

Bromegrass, *Bromus inermis* Leyss, was studied with respect to (a) the effects of nitrogen fertilizer, shade, shade combined with nitrogen fertilizer, and mixture with alfalfa upon the growth habits and chemical composition; and (b) the effects of length of day upon

such qualities and characteristics. The results may be summarized as follows:

Fertilization with nitrogen increased the rate of leaf production, height and total number of shoots, number of fertile shoots, and dry weight of tops, but decreased the number of rhizomes and weight of the underground parts.

Shade decreased the number of shoots, number of rhizomes, number of fertile shoots, and dry weight of all plant parts. It increased the number of elongated internodes and the height of the plant. The internodes were more uniform in length than those on shoots from other plots.

The associated growth of alfalfa with bromegrass decreased the number of shoots, number of rhizomes, and dry weight of the plants of bromegrass.

The nitrogen-fertilized plants and check plants at bloom stage were low in percentage of nitrogen and high in percentage of carbohydrates; however, the absolute amounts of both were highest in the nitrogen-fertilized plants. The shaded plants were high in percentage of nitrogen and low in percentage of carbohydrates as compared to the check plants.

Plants grown under short days (8.5 hours) produced a rosette type of growth and the shoots developed in a decumbent position. The plants grown under normal days (15 hours) and long days (18 hours) developed in an upright position, the long-day plants attaining a greater height than the normal-day plants.

The total number of shoots per plant was greatest under short days and least under long days. More fertile shoots were produced on the normal-day plants than under either the short or long day treatments.

The maximum number of rhizomes was produced under the normal day length in late spring or summer. The rhizomes attained the greatest size and length under the long days.

The dry weight of plant parts increased as the number of light hours per day was lengthened.

Both the percentage and absolute amounts of carbohydrates were highest in the long-day plants. The short-day plants contained the highest percentage of nitrogen; however, the absolute amounts were about the same under each length of day.

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LINKAGE BETWEEN THE MARTIN AND TURKEY FACTORS FOR RESISTANCE TO BUNT, *TILLETIA TRITICI*, IN WHEAT[1]

Fred N. Briggs[2]

As a result of investigations of the genetics of resistance to bunt, *Tilletia tritici*, in wheat, the author has found (2)[3] three major genetic factors for resistance to this disease which have been designated as the Martin (*M*), Hussar (*H*), and Turkey (*T*) factors, respectively. The Martin factor has been found alone in White Odessa, Banner Berkeley, Odessa, and Sherman wheats in addition to the Martin variety which is used as a tester for this factor (3). The Hussar factor has been found only in Hussar wheat, along with the Martin factor, but has been isolated in Selection 1403, which is used as a tester for this factor (1). The Turkey factor has been found alone in Turkey 3055, Turkey 1558, Oro, Turkey 1558B, and Turkey 2578. Turkey 3055 has been used as a tester for this factor (4).

In the investigation of resistance to bunt in a resistant variety the usual procedure has been to cross such a variety with a susceptible one in order to determine the number of factors present. At the same time, crosses have been made with the tester varieties to determine the identity of such factors, the absence of susceptible progeny in F_3 indicating the presence of the same factor in both parents. Crosses with tester varieties which show susceptible progeny usually have been examined to see if the number of susceptibles conforms to the number expected on the basis of independent assortment of the factors involved. The data from the individual crosses between varieties containing the Martin and Turkey factors appeared to conform to the 15:1 ratio which would be expected on the basis of two independent factors.

Recently, the author had occasion to re-examine the data from all the crosses involving the Martin and Turkey factors. The F_3 data from these crosses are shown in Table 1.

Resistant and segregating rows cannot be accurately separated, but susceptible rows can be identified with a good deal of certainty. With the exception of Martin×Turkey 1558 the observed numbers are in satisfactory agreement with the expected numbers calculated on the basis of the 15:1 ratio. The cross between Martin and Turkey 1558 had a P value of 0.03. However, it will be noted that all the deviations are in the same direction. The total X^2 value for all six crosses is 16.535 which give a P value less than 0.01. When the data from all the crosses are considered together there are only 25 susceptible rows where 53.4 are expected out of a total of 854. This deviation gives an X^2 value of 16.112 and a very low value for P. Calculating the linkage from the total population, a cross over of 34.22%

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication April 27, 1940.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 541.

TABLE 1.—F_3 *Data from the various crosses of wheat involving the Martin and Turkey factors for resistance to bunt.*

Crosses	Types of row	No. of F_3 rows observed	No. of rows expected 15:1 ratio	P	No. of rows expected 34.22% C.O.	P
Martin × Turkey 3055	Resistant and segregating	183	178.1		184.4	
	Susceptible	7	11.9		5.6	
	Total	190	190.0	>0.10	190.0	>0.5
Martin × Turkey 1558	Resistant and segregating	179	171.6		177.6	
	Susceptible	4	11.4		5.4	
	Total	183	183.0	>0.03	183.0	>0.5
Sherman × Turkey 3055	Resistant and segregating	136	131.2		135.9	
	Susceptible	4	8.8		4.1	
	Total	140	140.0	>0.05	140.0	>0.8
Martin × Oro	Resistant and segregating	101	97.5		101.0	
	Susceptible	3	6.5		3.0	
	Total	104	104.0	>0.10	104.0	>0.99
Martin × Turkey 1558B	Resistant and segregating	114	110.6		114.5	
	Susceptible	4	7.4		3.5	
	Total	118	118.0	>0.20	118.0	>0.7
Martin × Turkey 2578	Resistant and segregating	116	111.6		115.3	
	Susceptible	3	7.4		3.7	
	Total	119	119.0	>0.10	119.0	>0.7
Total all crosses	Resistant and segregating	829	800.6		829.0	
	Susceptible	25	53.4		25.0	
	Total	854	854.0	Very small	854.0	

was obtained. When the expected numbers of susceptible rows were calculated for the individual crosses using the above linkage value, they were in close agreement with those obtained. The P values are shown even though in a number of cases they were based on expected values of less than 5.

The number of rows for the individual crosses was too small to show that the deviations between the numbers of rows obtained and those expected on the basis of the 15:1 ratio are greater than might be

expected from chance. However, when all the data are considered together the deviation becomes very significant. This deviation may be accounted for by linkage between the Martin and Turkey factors. Using a cross over of 34.22%, the expected numbers for all crosses are much nearer those obtained than when the two factors are considered to be independent.

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FERTILIZING VALUE OF SPENT PHOSPHATE CATALYST[1]

G. S. FRAPS[2]

A CATALYST containing phosphoric acid is used in the manufacture of gasolene from petroleum. Several hundred tons of the spent phosphate catalyst may accumulate at a manufacturing point during the course of a year, and the question arose as to its suitability for use as a fertilizer. Chemical analyses and pot experiments were made to secure the necessary information.

CHEMICAL COMPOSITION AND AVAILABILITY

The chemical composition of six samples is given in Table 1. The analysis of the samples gives from 40.93 to 54.46% of total phosphoric acid (P_2O_5) with the exception of one sample which had been exposed to the weather for some months and contained only 24.14%. These analyses were made by the A.O.A.C. method of ignition with magnesium nitrate. When nitric and hydrochloric acids were used as a solvent, the amounts of total phosphoric acid found were both low and erratic, such as 30.15% compared with 40.93% by ignition with magnesium nitrate.

The catalyst was almost completely soluble in ammonium citrate by the official A.O.A.C. method. The catalyst therefore has a high content of available phosphoric acid.

Three analyses of the catalyst for silica gave from 56% to 58.8% which was made insoluble by evaporating the solution to dryness. It is acid, having an acid-base balance of 561A to 836A by the tentative A O.A.C. method. The analyses indicated that the spent catalyst has a high content of chemically available phosphoric acid.

TABLE 1.—*Chemical composition of spent phosphate catalyst*

Description	Total P_2O_5 %	Insoluble P_2O_5 %	Available P_2O_5 %	Silica %	Acid-base balance %	Total P_2O_5 acid-sol. %
Fresh not weathered	40.93	0.40	40.53	58.80	561A	30.15
Not weathered . .	54.46	0.40	54.06	—	—	35.96
Not weathered	54.16	0.31	53.85	—	678A	30.26
Not weathered	47.18	0.81	46.37	56.01	836A	—
Weathered..........	24.14	0.44	23.70	—	—	16.00
Not weathered .	45.68	1.07	44.61	57.18	745A	—

AVAILABILITY TO PLANTS

The availability of the phosphoric acid of the spent catalyst was compared with that of superphosphate by means of the usual pot experiments with plants, with the exception that the conclusions

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[2]Chief of the Division of Chemistry. Technical assistance in this work was rendered by T. L. Ogier and Dr. P. F. Macy.

are based upon the quantity of phosphoric acid taken up by the plants instead of on the dry weight of the plants.

The crops were grown in pots containing 2,000 grams of subsoil and 3,000 grams of pure quartz sand. The four soils used were as follows: Soil A, Randall clay, 7- to 17-inch depth, from Texas Substation No. 19, Carrizo Springs, Texas; soil B, Webb fine sandy loam, 10- to 17-inch depth, from Substation No. 19; soil C, Maverick fine sandy loam, 7- to 14-inch depth, from Substation No. 19; and soil D, Elwood fine sandy loam, 14- to 21-inch depth, from Fannin County. Each pot received 1 gram of ammonium nitrate and 1 gram of potassium sulfate. No other addition was made to two pots, while two other pots received additions of 0.100 gram available phosphoric acid (P_2O_5) as superphosphate and two more received 0.2037 gram available phosphoric acid in the form of spent catalyst. At the time the experiments were begun, the percentage of available phosphoric acid was not known on account of difficulties in the analysis.

Equal quantities of seed per pot were planted and the pots kept in a greenhouse and watered three times a week. After 2 months, the first crop of corn was harvested, the additions of fertilizer repeated, and a second crop of kafir planted. The kafir was harvested in 2 months. The crops were dried, weighed, and analyzed for phosphoric acid.

The dry weights of the crops are summarized and given in Table 2. The weights of the crops which received the spent catalysts are larger than those which received the superphosphate, but the quantity of available phosphoric acid added was also larger.

The results for comparative availability of the phosphoric acid of the two substances are also summarized in Table 2. For each soil, the average quantity of the phosphoric acid found in corn from the two

TABLE 2.—*Weights of crops produced and percentages of phosphoric acid recovered from superphosphate and spent phosphate catalyst.*

Soil	Crop	Dry weight of crop, grams			Phosphoric acid (P_2O_5) recovered, %	
		No treatment	Superphosphate	Catalyst	Superphosphate	Catalyst
A	Corn	5.5	28.7	30.0	36.6	31.3
	Kafir	12.7	29.5	31.2	59.7	48.8
B	Corn	1.8	16.9	29.7	27.4	26.5
	Kafir	4.0	28.1	33.3	64.8	53.5
C	Corn	2.1	21.1	27.5	27.7	26.2
	Kafir	2.4	10.7	12.1	31.9	21.9
D	Corn	2.6	9.0	10.4	15.2	17.3
	Kafir	6.4	24.7	27.6	38.9	34.7

pots which did not receive phosphates was subtracted from the average quantity in the corn which received phosphate, and the remainder was assumed to be the phosphoric acid taken up by the corn from the phosphate. This remainder was divided by the quantity of available phosphoric acid used in the fertilizer to secure the percentages taken from the phosphate used.

Since the tests were made with four soils, involving a crop of corn and a crop of kafir in each, eight comparisons were possible. The percentage of phosphoric acid removed by the crops from the spent catalyst was less than that removed from the superphosphate in seven of the eight tests, but the differences were not large in most cases. In evaluating these results, the fact must be considered that twice as much available phosphoric acid was added in the catalyst as in the superphosphate. Taking this into consideration, the conclusion can be drawn that the phosphoric acid of the spent catalyst has a high availability to corn and kafir, and that its availability is as high, or nearly as high, as that of superphosphate.

SUMMARY

Spent phosphate catalyst is a by-product derived from the manufacture of petroleum products. When fresh, it contains from 40 to 54% available phosphoric acid (P_2O_5), and about 58% insoluble material (silica). The weathered catalyst may contain only 24% phosphoric acid. It is acidic, having an acid-base balance equal to 561 to 836 pounds of calcium carbonate per ton. Ignition with magnesium nitrate gives correct results for total phosphoric acid, but solution in acids gives results which may be 10% too low The percentage of the phosphoric acid taken up by corn and kafir in eight tests on four soils was nearly as high as from superphosphate. The phosphoric acid of spent phosphate catalyst has a high order of availability to plants, being much like that of superphosphate.

THE ESTABLISHMENT OF BAHIA GRASS, *PASPALUM NOTATUM*[1]

GLENN W. BURTON[2]

DURING the past few years a number of cattle men in Florida and South Georgia have purchased and planted seed of Bahia grass, *Paspalum notatum*, Flugge. Most of this seed has not been scarified. It has been broadcast usually in fair to poor seedbeds and no effort has been made to cover the seed. Although some good Bahia grass pastures have been established in this manner, several years are required and some failures have been experienced. Low viability and poor adaptability of the seed planted, winter injury, and drought probably featured in some of these failures.

Numerous greenhouse studies[3] have demonstrated that Bahia grass seed germinating less than 5% in 3 months can be made to germinate over 50% in 10 days when properly scarified with sulfuric acid In an effort to determine the value of seed scarification in field plantings and to obtain some information on methods of establishment, the following field experiments were conducted at Tifton, Georgia, in 1939.

On March 28, 1939, scarified and unscarified seed of common Bahia, bulked seed harvested from locally grown plants which originated from foreign commercial sources, and Paraguay Bahia, the latter a cold-resistant strain having seeds about two-thirds the size of common Bahia, were planted in 3 x 42 foot plots on a well-prepared Tifton sandy loam in the manner described in Table 1. The scarified seed used in this study were placed in a small drum similar to one previously described by the author[4] and were treated for 25 minutes in crude H_2SO_4 used in the manufacture of superphosphate fertilizer (specific gravity 1 69, about 78% H_2SO_4). The fertlizer was distributed on the surface and raked in before the seed was planted. The "broadcast and harrowed" plot was raked after the seeding to simulate the covering which would have resulted from a light harrowing with a spike-toothed harrow. A columbia nursery drill was used to drill, cover, and pack the seed planted in rows.

In addition to the treatments described in Table 1, plots were established in which the same number of seeds were planted per linear foot in rows 1, 2, and 3 feet apart. All rows spaced 2 and 3 feet apart were cultivated with no hand weeding three times during the summer of 1939. The middle row of the 1-foot spacing could not be cultivated. The weed growth was cut back even with the tips of the grass leaves twice during the season.

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[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station at Tifton, Georgia, and the Georgia Experiment Station, Experiment, Georgia. Received for publication May 27, 1940.

[2]Associate Geneticist, U. S. Dept. of Agriculture, Tifton, Georgia.

[3]BURTON, GLENN W. Scarification studies on southern grass seeds. Jour. Amer. Soc. Agron., 31:179–187. 1939.

[4]*Loc. cit.*

TABLE 1.—*The influence of seed scarification and planting methods upon the establishment of common Bahia (C. B.) and Paraguay Bahia (P. B.), Paspalum notatum strains, as measured by seedling counts made on April 24, 1939, one month after planting.*

Treatment No.	Seeding rate, lbs. per acre	Fertilizer 7-14-7, rate, lbs. per acre	Depth seed were planted, inches	Method of planting	No. of seedlings per sq. ft. or per ft. of row		No. of seedlings per 100 seed planted	
					C.B.	P.B.	C.B.	P.B.
				Seed Not Scarified				
1	28	270	3/8	Drilled, covered, and packed	7	28	3.1	8.0
				Seed Scarified With H_2SO				
2	28	270	Surface	Broadcast and not harrowed	11	6	11.6	4.1
3	28	270		Broadcast and harrowed	40	39	42.1	26.5
4	28	270	Surface	Drilled on surface and packed	36	50	12.6	11.3
5	28	270	1/2	Drilled, covered and packed	71	152	24.9	34.5
6	28	270	1	Drilled, covered and packed	80	94	28.0	21.3
7	28	270	3/8	Drilled, covered and packed	89	139	31.2	31.5
8	28	None	3/8	Drilled, covered and packed	125	201	52.6	45.6
9	13	270	3/8	Drilled, covered and packed	51	101	39.0	49.8
10	13	None	3/8	Drilled, covered and packed	72	96	55.0	47.3
11	8.4	270	3/8	Drilled, covered and packed	35	71	41.2	54.2
12	8.4	None	3/8	Drilled, covered and packed	44	62	51.8	47.3

On March 30, two days after the planting was made, 0.14 inch of rain was recorded. Six-hundredths inch of rain fell on April 3 and 3.83 inches were recorded on April 6. A total of 6.41 inches of rain were quite well distributed over the period from March 28 to April 24. On April 24 the number of seedlings per square foot of the broadcast plots or per linear foot of row were counted in three random areas in each plot. The average of these counts for the various treatments, together with the calculated number of seedlings per 100 seeds planted, have been presented in Table 1.

A comparison of treatments 1 and 7 in Table 1 indicates that scarified seed of common Bahia produced over 10 times as many plants per 100 seeds planted as the unscarified seed. In agreement with our greenhouse studies, this field planting revealed that unscarified seed of Paraguay Bahia will germinate better than unscarified seed of common Bahia. Thus, scarification increased the germination of Paraguay Bahia only about four times.

Treatments 2 and 3 in Table 1 suggest that covering broadcast seed by harrowing will increase the number of seedlings produced per 100 seeds planted from three to six times. Plant counts made on three randomized areas in each plot on January 4, 1940, revealed an average of 9 plants of common Bahia and 11 plants of Paraguay Bahia per square foot in the "Broadcast and not harrowed" plot and 26 and 34 plants, respectively, in the "broadcast and harrowed" plots. Likewise, a comparison of treatments 4 and 7 in Table 1 proves quite conclusively that covering Bahia grass seed results in a substantial increase in the number of plants produced per pound of seed planted.

A study of the results obtained for the various depths of planting indicates that in this test planting the seed at a depth of 3/8-inch produced the most seedlings per 100 seeds planted. It is apparent, however, that planting the seeds 1 inch below the surface produced more seedlings per 100 seeds planted than surface planting (compare treatments 4 and 6 in Table 1). Thus, since the seed planted at a depth of 1 inch in this test germinated first, it would seem that seed planted in light sandy soils or during dry periods might well be placed an inch below the surface of the soil.

Table 1 shows that fertilizer applied at the time of seeding, although not placed in intimate contact with the seed, frequently decreased the germination of Bahia grass seed. These results suggest that drilling commercial fertilizer and Bahia grass seed together in the same row may reduce its germination materially.

In this test scarified common Bahia grass seed planted at the rate of 8.4 pounds of seed per acre in 3-foot rows produced an average of 44 seedlings per linear foot or row. Obviously good seed properly scarified could be planted in 3-foot rows in a well-prepared seedbed at rates much lighter than 8.4 pounds per acre.

The influence of various treatments upon total top growth in 1939 was determined in January 1940 by digging up all plants in 3 feet of each row, removing the roots, drying, and weighing the tops. These yields showed the following relationships: Rows grown from scarified seed yielded about twice as much as rows from unscarified

seed. The better stand and earlier establishment of the rows from scarified seed were largely responsible for this difference. Since the rows seeded at 8.4 pounds per acre yielded as much as those seeded at 28 pounds per acre, it is apparent that the heavier seeding represented in this case a waste of 19.6 pounds of seed per acre. Fertilization at the time of seeding, while increasing the average yield of all rows fertilized, failed to do so consistently.

That the yields of the middle rows in the 1-, 2-, and 3-foot spacings would differ was suggested by the appearance of these plots on July 20, 1939, as shown in Fig. 1. Since the 2- and 3-foot spacings yielded

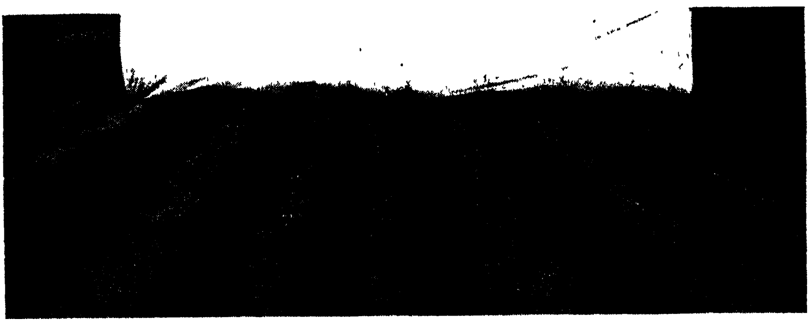

FIG. 1.—The influence of row spacing and cultivation upon the growth of Bahai grass. On the left, the 1-foot spacing, center row not cultivated; in the center, the 2-foot spacing; on the right, the 3-foot spacing. Photographed four months after seeding.

practically the same per linear foot of row, it is evident that the 2-foot spacing actually produced 50% more top growth per square foot than the 3-foot spacing. On the unit area basis the 2-foot spacing produced 4 times as much top growth as the 1-foot spacing. Since the 2-foot spaced rows were cultivated and the middle 1-foot row was not, most of this increase must be credited to three cultivations made during the summer. As shown in Fig. 1, the rows spaced 2 and 3 feet apart produced seed equally well in 1939, while the middle row of the 1-foot spaced rows formed practically no seed heads.

On April 28, 1939, seed of six promising grasses at Tifton, Georgia, were planted in 25-foot rows in quadruplicate, in a well-prepared Tifton sandy loam. Abundant rainfall followed, favoring the germination of all seeds planted. For these six grasses the following dates of emergence were recorded: Common Bahia grass (scarified seed), May 7; *Paspalum malacophyllum* Trin., May 7; Paraguay Bahia grass (scarified seed), May 11; Vasey grass, *Paspalum urvillei* Steud., May 13; Dallis grass, *Paspalum dilatatum* Poir, May 15; and carpet grass, *Axonopus affinis* Chase, June 5. Thus there is little doubt but that good Bahia grass seed, when properly scarified, will germinate as soon, if not sooner, than other grasses such as carpet and Dallis grass now being planted in this area.

SUMMARY AND CONCLUSIONS

Since it is recognized that preparing good seedbeds, drilling and covering seed, and cultivation will be highly impracticable in many areas where Bahia grass will be planted, the results presented here will have their principal value in assisting the formulation of a planting procedure for each set of conditions. With full recognition of these specific problems these results would seem to justify the following conclusions: Regardless of the manner in which the seed is planted, acid scarification will greatly increase the number of plants obtained per pound of seed. With the present high price of seed, drilling seed ¼ inch to 1 inch deep in well-prepared seedbeds where possible, or covering seed by the use of disk harrows, etc., in areas where good seedbeds cannot be made should pay dividends. For those interested in seed production, or for farmers with more time than cash, drilling 4 to 6 pounds of good scarified seed in rows 2 feet apart followed by several cultivations should prove to be a very economical method of establishing the grass. If scarified seed of Bahia grass is planted properly, there is no doubt but that it can be established from seed as readily as other grasses grown in this area.

NOTE

A SATISFACTORY GRINDER FOR PREPARING PLANT TISSUE FOR RAPID CHEMICAL TESTS

ONE of the obstacles in the way of the advancement of rapid chemical analyses in plant tissue tests has been a satisfactory method of obtaining an accurately extracted sample By the use of a "liquifier" (Waring Corp., 1697 Broadway, N. Y)[1] a most satisfactory emulsified sample can be obtained.

The author has found the following procedure satisfactory. Place 5 grams of roughly chopped plant tissue or stems (even very woody tissue is readily emulsified) in the container, add 100 mls of sodium acetate solution (pH 5.0), 0.125 N for sodium and 0.167 N for acetate, and ¼ teaspoonful of charcoal (Darco brand) and run the machine from 3 to 5 minutes. The liquified mass is then filtered through No. 1 Whatman filter paper.

Tests for various constituents are carried out as described for soil tests in Bulletin 95, Virginia Truck Experiment Station. However, in the case of potash further dilution of the extract is necessary.—JACKSON B. HESTER, *Soil Technologist, Department of Agricultural Research, Campbell Soup Co., Riverton, N. J.*

[1]Several other makes of similar equipment are available.

AGRONOMIC AFFAIRS

CHECK SOILS FOR COLLABORATIVE SOIL TESTING

A SERIES of 31 check soils was assembled last year by the Sub-committee on Soil Testing of the Fertilizer Committee of the American Society of Agronomy. Sets of samples may be obtained upon request to Dr. H. G. Byers, Soil Chemistry Division, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. There is no charge, except that the package is sent by express, collect.

Collaborators obtaining sets of the check soils are expected to send copies of their results to M. F. Morgan, Connecticut Agricultural Experiment Station, New Haven, Conn., Chairman of the Sub-committee. They will be supplied with preliminary reports of "composite" results to date and will receive copies of all further data concerning the various soils. The Sub-committee on Soil Testing plans to present a detailed study of these results at the winter meeting; hence, it is urgent that reports be filed during the next two or three months. Results received after October first cannot be included. Twenty-six collaborators have already reported, but it is hoped that the data of at least twice this number will be available in the final tabulation.

NEWS ITEMS

THE following changes became effective May 1, 1940, in the Agronomy Departments of the Ohio Agricultural Experiment Station and the Ohio State University: Robert M. Salter has been appointed Associate Director of the Ohio Agricultural Experiment Station. Dr. Salter continues as Chief in Agronomy at the Experiment Station. At the Ohio State University R. D. Lewis has been appointed Chairman of the Department of Agronomy and continues as Associate in Agronomy at the Experiment Station. C. A. Lamb, Associate in Agronomy at the Experiment Station, also has been appointed a member of the teaching staff (Cereal Crops) of the Department of Agronomy of the Ohio State University. Effective July 1, 1940, Robert Q. Parks becomes an Assistant in Agronomy (Soil Fertility) at the Experiment Station and Instructor in Agronomy at the University.

The cooperative relationships between the Departments of Agronomy of the Ohio Agricultural Experiment Station and the Ohio State University are to be continued as in the immediate past.

PROFESSOR O. MCCONKEY of the Department of Field Husbandry, Ontario Agricultural College, has been called to mobilize a battery of field artillery in the Royal Canadian Artillery. Major McConkey may be reached through the Ontario Agricultural College at Guelph.

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THE ROLE OF SOIL ORGANIC MATTER IN REFORESTATION[1]

S. A. WILDE AND W. E. PATZER[2]

THE importance of soil organic matter in the promotion of soil fertility has received the attention of both practical and scientific agriculturists for many centuries (10).[3] Nevertheless, there still exists surprisingly little information on the role which soil organic matter plays in practical silviculture, particularly in the survival and growth of forest plantations. Why forestry research and reforestation practice in both America and Europe have neglected this important factor is difficult to comprehend. The indifference may be attributed to comparatively limited experience in the reforestation of old cut-over areas, the complicating co-influence of mineral colloids, occurrence of organic matter as incorporated humus as well as surface litter, certain analytical difficulties in the determination of organic matter, and fairly satisfactory growth of some mycorrhizal species on humus-deficient soils.

At the present time, reforestation in this country is, in the main, practiced on cut-over or burned-over lands depleted of organic matter and therefore greatly reduced in absorbing capacity and nutrient content. A large portion of the area available for reforestation is comprised of coarse sandy soils having a negligible content of mineral colloids; the content of organic matter in such soils is particularly of great importance. Some humus-loving species, such as spruce and white pine, seem to require for their successful growth a certain amount of organic matter aside from the supply of water and mineral plant nutrients.

These considerations served as an impulse in undertaking the present study. Within available means, an effort was made to establish a

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[2]Associate Professor and Chemist, respectively. The writers are indebted to Mr. R. W. Knutson, U. S. Forest Service, Region 9, and Mr. S. B. McCoy, Wisconsin Conservation Department, for their wholehearted cooperation in different phases of this study.

[3]Figures in parenthesis refer to "Literature Cited", p. 562.

general relationship between the content of soil organic matter and the productivity of cut-over lands, to correlate organic matter content with planting possibilities, and to work out an analytical procedure acceptable to forestry practice. The investigations were largely confined to central and northern Wisconsin with four silviculturally important conifers, namely, jack pine, *Pinus banksiana*, red pine, *P. resinosa*, white pine, *P. strobus*, and white spruce, *Picea glauca*.

RELATION OF SOIL ORGANIC MATTER TO PRODUCTIVITY OF CUT-OVER LANDS

A study was made of the organic matter and nutrient content of outwash and pitted outwash sandy soils derived largely from granitic rocks. The geological origin and textural characteristics of these deposits were believed to be sufficiently uniform to permit an investigation of the relations between organic matter, total nitrogen, available phosphorus, and available potassium. The total number of samples analyzed exceeded 40. In order to get soils with higher contents of organic matter, several selectively logged areas were included in the study. Organic matter was determined either by the standard chromic acid procedure (3), or by a modification of Schollenberger's (7) method described in this paper. Kjeldahl (A. O. A. C., 2), Truog (8), and Volk-Truog (9) methods were used for the determination of total nitrogen and available phosphorus and potassium, respectively. The results related to the 7-inch surface layer of soil are presented in Figs. 1 and 2.

The results suggest that the deficiency of all nutrients becomes especially acute when the content of organic matter drops below 2%. According to the agronomist's saying, "Nitrogen spells organic matter." In sandy forest soils, with their revolving fertility renewed through the annual leaf-fall, the organic matter content appears to be nearly synonymous with the content of all available nutrients.

Organic matter retains considerable amounts of water (6). Although a portion of this water is not available to trees (4), the soils with a high organic matter content may be less subject to drought injury than humus-deficient soils.

RELATION OF SOIL ORGANIC MATTER CONTENT TO SURVIVAL AND GROWTH OF PLANTATIONS

The limited number of plantations having uniform physiographic conditions makes it very difficult to study the growth of seedlings in relation to the organic matter content of soil on a statistical basis. This problem involves not only the co-influence of site factors, but the occurrence of critical weather conditions, origin of stock and its handling in the field.

The first attempts of the writers, confined to the area of central Wisconsin, gave but one result worthy of consideration, namely that jack pine and red pine deteriorate in growth when the content of soil organic matter drops below 0.5 and 2.0%, respectively. The wind-eroded "blow holes" occurring in spots within plantations furnished material from which this information was derived (Fig. 3).

In the fall of 1939, several members of the U. S. Forest Service called the attention of the writers to the extremely low content of organic matter in soils of the Bayfield Barrens, Chequamegon National Forest. This area presented nearly ideal conditions for the study of the problem. It comprises thousands of acres of podzolized sands on which reforestation has been carried on since 1930, and a complete history of the plantations was available.

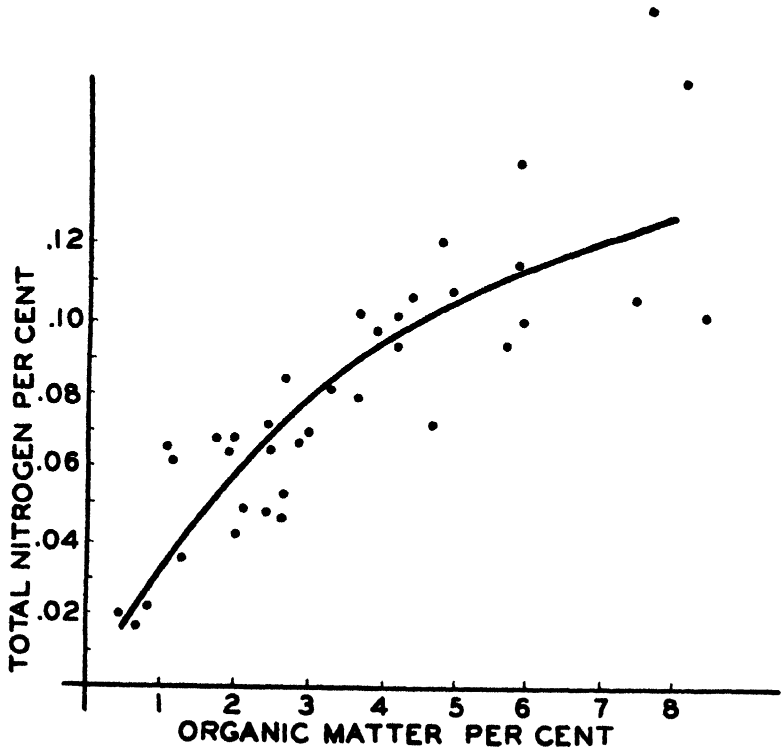

FIG. 1.—Relation of total nitrogen to organic matter in cut-over sandy soils of Wisconsin (Plainfield and Vilas series).

The collection of samples was limited primarily to plantations characterized by either poor or very satisfactory tree growth. A few plantations established by the State Forestry Department in adjoining counties were also included in this study. The results of soil analyses and the corresponding data for the survival and average annual growth of jack and red pine are given in Figs. 4 and 5.

Although the data vary considerably, they indicate an adverse influence of deficient organic matter upon both survival and rate of growth of the species studied. The results obtained from soils with a low content of organic matter are, of course, of greatest practical significance. The need for further observations, with a much greater number of sample areas, is nevertheless obvious.

RELATION OF SOIL ORGANIC MATTER CONTENT TO PLANTING POSSIBILITIES

The results obtained in the study of jack and red pine plantations, as well as some incidental observations of white pine and white spruce plantations, suggest that the following minimum contents of soil organic matter are required by these species: Jack pine, 0.6%; red pine, 1.8%; white pine, 2.5%; white spruce, 3%. These figures ap-

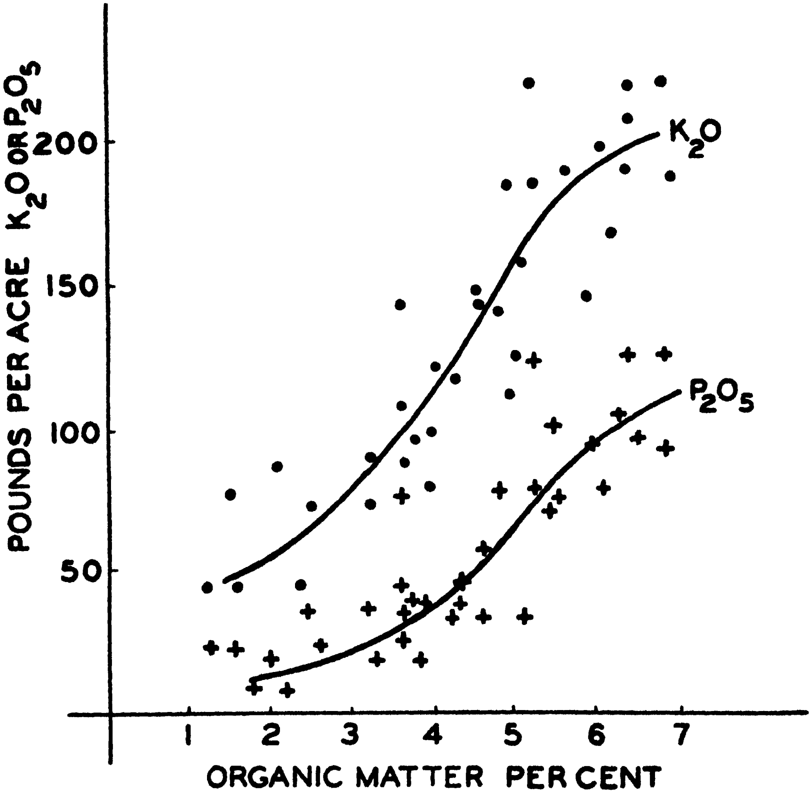

FIG. 2.—Relation of available phosphoric acid and available potash to organic matter in cut-over sandy soils of Wisconsin (Plainfield and Vilas series).

proximate the *absolute minimum requirements* which should be respected in planting, regardless of other conditions. A sufficiently high content of organic matter is of particular importance in the growth of spruce, i.e., a species with saprophytic tendencies.

Since the influence of organic matter supplements, within certain limits, the effect of mineral colloids (11), a coordinated consideration of both of these factors should provide a wider selection of planting sites, and, at the same time, would give more assurance of success.

General observations indicate that the absorbing or base exchange effects of soil organic matter are at least two and one-half times as

FIG. 3.—Fourteen-year old red pine plantation on outwash sand deficient in organic matter; average height 6 feet. Red pine plantations of the same age on more productive soils in the vicinity attained an average height of 15 feet or more.

great as those of fine soil material, i.e., material less than 0.05 mm in diameter. Hence, as regards these effects, it may be estimated for practical purposes that one per cent of organic matter is equivalent to 2.5% of fine soil material. This implies that a considerably lower content of mineral colloids is adequate for successful planting on soils high in organic matter. For example, on such soils under Wisconsin conditions, the minimum contents of the fine soil material

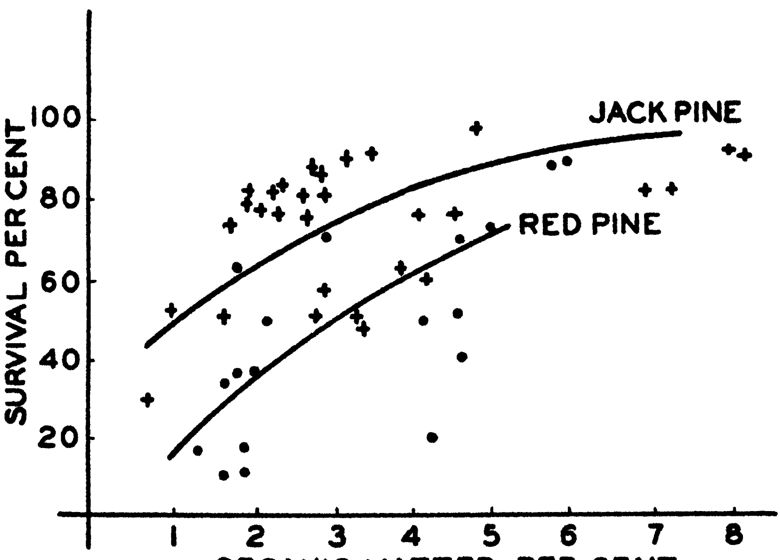

FIG. 4.—Relation of survival of jack pine and red pine plantations to the content of organic matter in podzolic sandy soils of northern Wisconsin. The general trend is indicated by free-hand curves.

ordinarily necessary could be lowered to the following values: Jack pine, 3%; red pine, 7%; white pine, 12%; white spruce, 25%.

A scheme of planting possibilities for four coniferous species under Wisconsin climatic conditions and for soils not influenced by ground water is given in Fig. 6. The slanted lines represent the minimum acceptable ranges of fine soil material and organic matter for each species. The ordinate and abscissa values for any point on a species line give the minimum acceptable values of each constituent for that

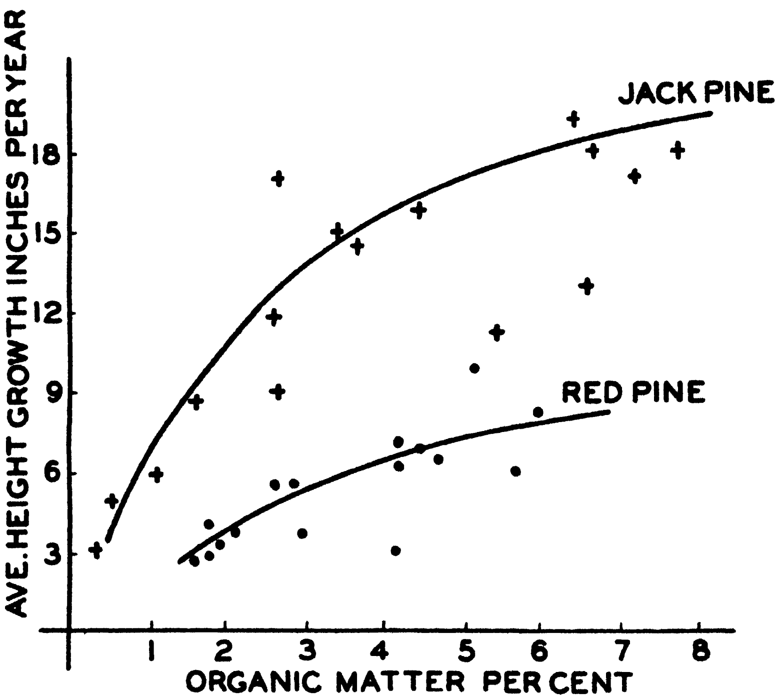

FIG. 5.—Relation of height growth of jack pine and red pine plantations to the content of organic matter in podzolic sandy soils of northern Wisconsin. The general trend is indicated by free-hand curves.

species. Therefore, the lines of species which touch the intersection of perpendiculars erected from the coordinates, or fall within the area enclosed by the perpendiculars, indicate that these species are suitable for planting on the soil in question. A transparent right triangle will be found helpful in using the diagram.

For example, if the soil analyzes 20% of silt and clay and 2.7% of organic matter, then the site is suitable to jack pine, red pine, and white pine, but not white spruce. The graphs may also be used in a somewhat different manner. Suppose the soil of a large outwash tract is known to contain about 10% of silt and clay particles; then the sites suitable to red pine should have at least 3% of organic matter.

METHOD OF SOIL SAMPLING

Sampling for the determination of the organic matter content in forest soils presents its own problem. In weakly podzolized or in brownearth soils with a mull type of humus, the litter decomposes rapidly and the organic matter is thoroughly mixed with the mineral soil. On the other hand, in podzol soils organic matter occurs as a

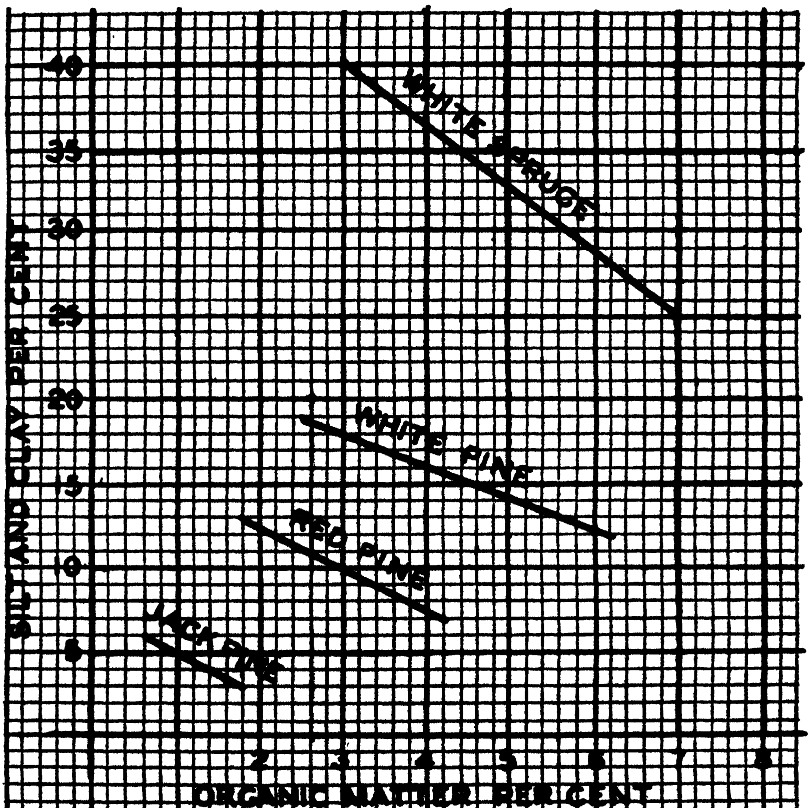

FIG. 6.—Planting possibilities of northern conifers in relation to soil texture and content of organic matter under Wisconsin conditions. The lines of species which touch the intersection of perpendiculars erected from the coordinates, or fall within the area enclosed by the perpendiculars, indicate that these species are suitable for planting on the soil in question.

surface deposit, including undecomposed litter and a partly decomposed duff layer underlain by a humusless leached horizon. In between these two extremes, there are numerous transitions, i.e., soils in which some organic matter occurs as free remains and some is incorporated with the mineral soil. It is obvious that in sampling such heterogeneous soils proportionate amounts of material cannot be secured by means of an auger or spade. The sampling by separate horizons involves difficulties of measuring the thickness of the horizons, extra

determinations, and rather lengthy calculations. Therefore, the most suitable method seems to be the use of a sampling tube which removes a representative cross-section of the entire soil profile to a definite depth.

In an attempt to devise a tool adapted to sampling, a number of modifications have been made and tried in the field. The combination of the soil auger handle with Pessin's tube (5), made of black iron pipe, proved to be the most successful. The best dimensions appeared to be a diameter of one-inch bore with a one-half inch slit; tubes of greater size caused difficulties in gravelly soils, whereas tubes of smaller size became plugged by the soil and acted as a plunger. A sampling length greater than 7 inches was found unnecessary, as the infiltration of humus seldom exceeds 6 inches. Fig. 7 shows the successful model together with other models which proved to be unsatisfactory

The sampling is accomplished by pressing the tube into the soil. In stiff soils, a rotating movement in auger-like fashion may be helpful, but it is usually better to remove what soil has collected and continue in the same hole with the emptied tube. The removal of soil is facilitated by the use of a bent piece of iron which fits the slit.

The soil samples are placed in half-pint cardboard boxes. Two borings usually give a sample of sufficient size.

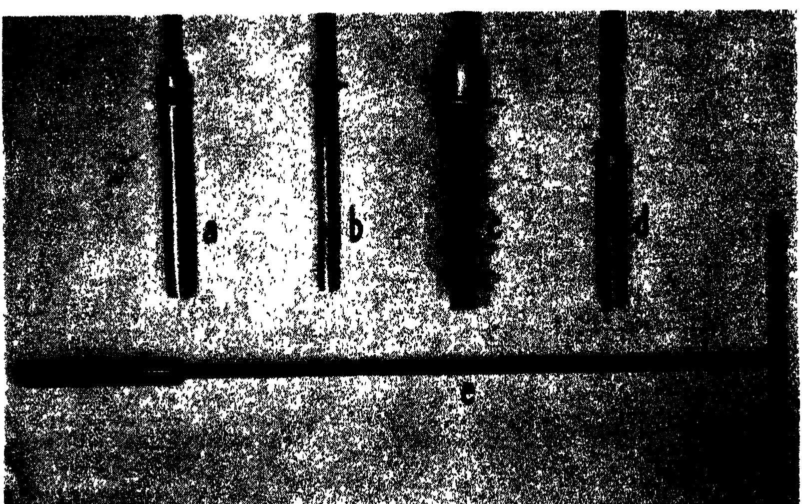

FIG. 7.—Models of sampling tubes tried: (a) A modification of King's tube provided with a swinging door to facilitate the removal of soil; the door was found to be unnecessary; (b) A narrow, half-inch bore tube which would be ideal for collecting samples from nursery beds, but often becomes plugged with soil and acts as a plunger; (c) Auger-like tube; proved to be an expensive and inefficient tool; (d) Shortened Pessin's tube of one inch bore with half-inch slit; found to be a simple and efficient sampler; (e) The same tube on a 2-foot long auger rod; shorter rods caused inconvenience in sampling.

PROCEDURE FOR ORGANIC MATTER DETERMINATION

A survey (1) of the existing procedures for the determination of soil organic matter indicated that the chromic acid titration method devised by Schollenberger (7) has, because of its simplicity, many advantages for practical work. The following adaptation of this method has been found to give reliable data and is recommended for rapid, approximate work in reforestation practice:

The air-dry soil sample is passed through a 20-mesh screen. With gravelly soils, the percentage of coarse material is determined on a gross balance in the usual manner. A representative portion is ground with mortar and pestle or with a steel rocker on an extra hard steel plate until all of the particles pass through a 100-mesh screen. A measuring spoon, calibrated to deliver a one-half gram sample, is filled heaping full of the soil. After packing the soil with a spatula, the spoon is struck off level full. The sample is transferred to a dry 1 x 6 inch Pyrex test tube. One cc of potassium bichromate solution is measured with a pipette and transferred to the tube. Fifteen cc of the sulfuric-phosphoric acid mixture are added, thoroughly washing down the soil particles.

The tube is placed for 10 to 15 minutes in a bath of 85% phosphoric acid heated to 160° C. The contents of the tube are agitated occasionally. Ordinarily, a battery of twelve tubes is digested in the same bath. After digestion is complete, the tube is removed, allowed to cool for several minutes, and then placed in flowing cold water. The cooled contents of the tube are poured into a beaker. Four rinsings of the tube with water are necessary for complete transfer. The solution in the beaker is diluted to 200 cc. Five drops of diphenylamine indicator, and a quarter teaspoonful of sodium fluoride powder are added. Then 0.2 N ferrous ammonium sulfate solution is added slowly from a burette with stirring until a clear dark blue color develops. Another drop of the ferrous ammonium sulfate solution is added and the contents are vigorously stirred for 30 seconds or more.

This process is continued until the blue color changes to green. A blank (without soil) is prepared using the same amounts of bichromate solution and acid mixture as in the regular test. Titration is made in the usual manner. The difference between the titration figures of the blank and unknown solution multiplied by 0.125 and divided by the weight of the sample in grams gives the percentage of organic matter.

If the soil sample contains more than 2.5% of organic matter, 2 cc of bichromate solution and 30 cc of acid mixture should be used in the digestion. The digested solution should then be diluted to 400 cc. Soils having contents of organic matter higher than 5% will require still greater amount of reagents, and hence greater dilution. Experience will teach the desirable amount of acid needed under various conditions.

The accuracy of the method as regards duplication of results is illustrated by the data of Table 1.

If titration is inconvenient, it may be replaced by a colorimetric procedure. The cooled, digested solution is diluted to 75 cc and allowed to settle. The reduction of chromic ions (orange) to the chromous state (green) produces a variation of color ranging from bright

TABLE 1.—*Duplicate determinations of the content of organic matter in cut-over sandy soils by the modified Scholenberger chromic acid reduction method.*

No. of soil sample	1st determination %	2nd determination %	Difference %	No. of soil sample	1st determination %	2nd determination %	Difference %
1	1.25	1.24	0.01	9	2.20	2.06	0.14
2	1.71	1.71	——	10	3.03	3.30	0.27
3	1.53	1.53	——	11	2.15	2.05	0.10
4	1.90	1.86	0.04	12	2.55	2.60	0.05
5	3.00	3.02	0.02	13	1.55	1.70	0.15
6	4.22	4.12	0.10	14	1.60	1.45	0.15
7	4.15	4.50	0.35	15	1.95	1.95	——
8	4.57	4.50	0 07	16	2.75	2.68	0.07

orange to bluish-green. Comparison of the unknown solution with a set of standards, or with a suitable color chart gives the content of organic matter within an accuracy of about 0.25%. With certain adjustments, the comparison of colors may be facilitated by the use of a photoelectric cell.

REAGENTS NEEDED FOR ORGANIC MATTER DETERMINATION

Potassium bichromate solution.—Dissolve 9.807 grams of oven-dry $K_2Cr_2O_7$ in 75 cc of water and make up to 100 cc in a volumetric flask. Keep this solution tightly stoppered to prevent evaporation.

Sulfuric-phosphoric acid mixture.—Add by volume 2 parts of concentrated sulfuric acid, C. P. grade, to 1 part of 85% phosphoric acid U.S.P. grade.

0.2 N ferrous ammonium sulfate solution.—Dissolve 78.44 grams of $FeSO_4(NH_4)_2SO_4.6H_2O$ in 500 cc of water containing 20 cc of concentrated H_2SO_4 and make up to 1 liter. Keep this solution in a tightly stoppered brown bottle.

Diphenylamine indicator.—Dissolve 0.5 gram in 100 cc of concentrated H_2SO_4 and transfer into a 200 cc beaker containing 20 cc of water. Store in a tightly stoppered brown bottle.

DISCUSSION

In the past, the application of soil analysis in the selection of planting sites has been limited largely to two factors, namely, reaction and content of mineral colloids. The lack of knowledge concerning the soil organic matter content led to the use of estimated values. As a consequence, the sites with a high content of organic matter were not fully utilized, whereas on those with a low content, planted stock was exposed to the danger of drought or malnutrition.

During the past few years a number of foresters have questioned the adequacy of a knowledge of the mineral colloid content alone and have emphasized the role which organic colloids may play in the survival and growth of plantations. Considering the cost of reforestation, as well as the discouraging effects produced by failure or poor growth of plantations, it seems well worthwhile to include the de-

termination of soil organic matter as a routine requirement in the future selection of planting sites. In the course of a few years, sufficient information should thus be accumulated to determine the full value and significance of soil organic matter content in different regions.

A problem which is likely to draw the attention of many foresters is the influence of soil organic matter upon the growth of trees planted in furrows. Deep furrowing removes the entire humus layer of soil and thus apparently deprives the seedlings during their early growth of the benefit derived from organic matter. However, a considerable portion of the organic matter is gradually washed into the furrows. Moreover, in a relatively short time, the spreading root systems utilize the water and nutrients retained in the humus layers of the surrounding undisturbed ground. Therefore, it does not seem quite justifiable to overlook the content of organic matter even when deep furrowing is planned.

The attention of the writers has been called to the exceptionally good growth obtained with pine seedlings planted in deep excavations along highways where as much as two feet of soil had been entirely removed. It seems that the explanation lies in the fertilizing effect of soluble salts and humus washed into these depressions by runoff. The absence of competing vegetation, protection from wind, and a favorable content of moisture are other contributing factors.

A few incidental observations in hilly regions have indicated that the organic matter content of cut-over soils is greater on northern than on southern exposures. It is probable that the influence of several site factors, such as light, temperature, and moisture, common to various topographical aspects, will be expressed by the data from soil organic matter determinations.

The determination of organic matter content may also serve as an index of soil depletion resulting from grazing, scraping of litter, or burning, and may be very useful in the management of woodlot soils.

SUMMARY

The content of soil organic matter was studied in relation to reforestation practice. Investigations were confined to central and northern Wisconsin, and involved four important conifers, *Pinus banksiana*, *P. resinosa*, *P. strobus*, and *Picea glauca*. A close relationship was found between the content of organic matter and that of total nitrogen, available phosphorus and available potash in outwash and pitted outwash sandy soils derived from granitic rocks. The study of plantations showed a pronounced increase in the rate of height growth of jack pine and red pine due to a higher content of organic matter. A general tendency for the increased survival of seedlings was observed on soils high in humus, but the correlation was not significant on the basis of the present observations.

Because the influence of organic matter within certain limits supplements the effect of mineral colloids, both factors were given consideration, and suitable standards are suggested as a guide in the selection of planting sites.

A technic of sampling forest soil was worked out and the Schollenberger's chromic acid titration method was adapted for use in forestry practice.

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THE AVAILABILITY OF REPLACEABLE POTASSIUM TO TOMATOES ON A SASSAFRAS SANDY LOAM[1]

JACKSON B. HESTER AND F. A. SHELTON[2]

IT IS known that a large amount of potassium is used in the production of a tomato crop. In certain sections of the country it has been customary for the growers to apply large amounts of high potash fertilizers before planting. It is a practice for some of them to mix the fertilizer in the row and allow it to be exposed to the elements for a period of several days before planting. If a good rain occurs between the time the fertilizer is applied and the plants are set, no injury is likely to occur to the transplants but, when there has been little or no rain, often much difficulty is experienced in obtaining a stand. While it is known that many of the soluble salts in mixed fertilizers will cause this trouble, one of the chief ones is muriate of potash. If potassium remains available to tomatoes in the replaceable state, high salt concentration in the soil can be avoided. A series of experiments were designed to give information upon the availability of replaceable potassium and potassium added to a soil from soluble salts.

PREPARATION OF POT CULTURES

For use in these experiments a virgin Sassafras sandy loam, analyzing 17% clay in the topsoil and 24% clay in the subsoil, was obtained from a woods near Moorestown, N. J., some of the chemical characteristics of which are shown in Table 1. A series of 2-gallon coffee-urn lining pots were prepared by tamping in 7,000 grams of subsoil (Fig. 1) comparable to the compactness under natural conditions and without any treatment of chemicals.

TABLE 1.—*Some chemical analyses of the Sassafras sandy loam soil used in the experiments.*

Horizon	pH in H_2O	pH in KCl	Organic matter, %	N, %	Replaceable M.E. per 1,000 grams of soil*		
					Ca	Mg	K
A	4.9	4.25	4.75	0.165	15.7	2.1	1.4
B	4.8	4.25	1.60	0.072	5.0	2.2	0.7

*Obtained by slowly leaching 50 grams of soil with 500 milliliter of N/2 ammonium acetate and chloride (pH 7.0).

Seven thousand grams of topsoil (the section under the heavily infiltrated organic layer) were limed with 40 grams of 200-mesh dolomitic limestone, a sufficient quantity to bring the pH value to approximately 6.1. Varying amounts of muriate of potash were likewise mixed with the topsoil before it was placed in the pot and, in this discussion, will be referred to as the odd-numbered pots or leached series. The soil was thoroughly moistened and allowed to stand a week and then

[1]Contribution from the Agricultural Research Department, Campbell Soup Company, Riverton, N. J. Received for publication March 29, 1940.
[2]Soil Technologist and Assistant, respectively.

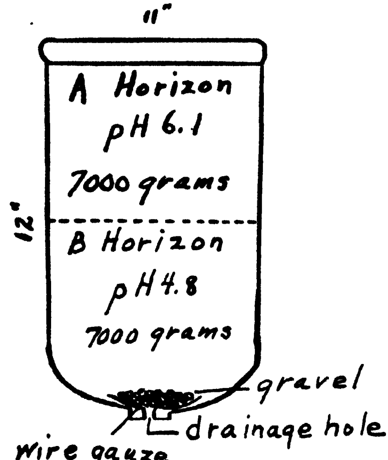

FIG. 1.—Giving the dimensions of the pot and the placement of the soil in the pot.

leached with rain water until approximately all of the chlorides were leached from the soil. This required the addition of sufficient water to give a leachate of 6 liters. A composite sample of this leachate was subjected to an analysis for chlorides, potassium, calcium, and magnesium.

The pots designated as the even-numbered or unleached series were then prepared the same as the odd-numbered pots with the exception of the potassium. This, in the muriate form and in amounts equal to that remaining in the odd-numbered pots after leaching, was then mixed with the topsoil in the even-numbered pots. In the odd-numbered pots the potassium was in the exchange complex of the colloid and in the even-numbered pots in the form of the chloride, except that certain exchange reactions between calcium and magnesium had no doubt taken place.

RESULTS OF LEACHING

Shown in Table 2 are the results of the analyses from the leaching experiment. It is well to remember that the high potassium contents represent very large applications of potassium, but not uncomparable to the concentrations in row applications of high potash fertilizer mixtures. In the low applications only relatively small amounts of potassium were leached from the soil (6 to 13% of the total added) but in the extreme applications as much as 48% of the potassium was leached. Later, it will be shown that a part of the potassium had collected in the subsoil. Practically all of the chlorides in the form of calcium and magnesium chloride, however, were leached out of the soil by the treatment even in the heaviest applications.

CROPPING PRACTICES

Finally, after the leached soils had come to optimum moisture content (14 to 16%) for crop growth, three vigorous, but small, Rutgers tomato plants were set in each pot. While the salt concentration of some of the pots was high, no difficulty was experienced in getting the plants to live. All plants were fertilized alike with ammonium nitrate and ammonium phosphate. The acidity in these chemicals was neutralized by the addition of lime and all chemicals were added in small portions at first. The pots were watered with rain water for optimum moisture but never sufficient to produce leaching. Finally, when the first crop was mature, the plants were harvested and yield records obtained. A second crop was planted immediately and fertilized similar to the first crop. Upon maturing, the plants were harvested and yield records obtained (Fig. 2).

TABLE 2.—*Results from the leaching procedure.*

Pot No.*	Percentage of added potassium leached	Milligram equivalents per pot		
		Potassium remaining of that added	Chlorides remaining	Calcium and magnesium leached
1	—	-2	0	6
2	—	0	8	0
3	6	63	1	54
4	—	63	71	0
5	13	117	0	115
6	—	117	125	0
7	27	195	0	215
8	—	195	203	0
9	36	340	10	322
10	—	340	348	0
11	47	558	0	564
12	—	558	566	0
13	48	1,067	56	997
14	—	1,067	1,067	0

*Odd-numbered pots leached until 6 liters of rain water passed through the soil. Even-numbered pots not leached.

The yield records for both crops were totalled and these results are shown in Fig. 3. These data bring out three significant facts. First, the yield of fruit of the leached series exceeded that of the unleached series at the higher applications of potassium, the yield increasing as the potassium increased; second, in the leached series the production of fruit was stimulated over vegetative growth where the higher amounts of potassium were present; and third, in the unleached series the highest quantity of soluble salts gave the lowest fruit formation in relation to vegetation; in other words, a less efficient plant.

AVAILABILITY OF POTASSIUM

The plant material from the two previously mentioned crops was analyzed for potassium and these data are summarized in Table 3.

FIG. 2.—Showing the response of tomatoes to potash. Pot 30, no KCl; pot 32, 78 M.E. KCl; pot 41, 1,082 M.E. K clay; and pot 42, 1,082 M E. KCl.

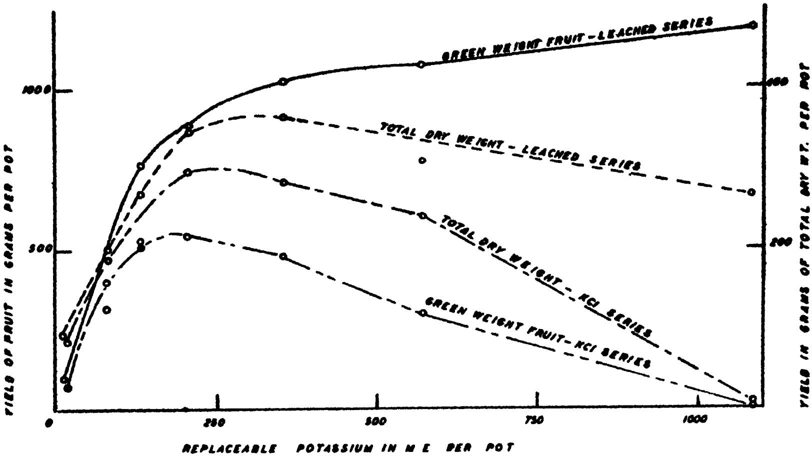

FIG. 3.—The influence of K clay and KCl upon the yield of tomatoes and vegetative growth.

These data bring out the fact that all of the replaceable potassium in the topsoil was absorbed by the plants in pots 1 and 2, but in no other case was all of the added and original replaceable potassium taken up by the plants. Through pot 6, the potassium absorbed from the unleached soil actually exceeded that of the leached soil, although the yield of pot 6 did not exceed that of pot 5; however, beginning with pots 7 and 8 the salt concentration was toxic and less potassium was absorbed from unleached than from leached pots.

TABLE 3.—*Availability of potassium to tomatoes.*

Pot No.	M.E. of K per pot		Yield in grams per pot		M.E. of K per pot		
	Total	Added and replaceable	Green weight of fruit	Total dry weight	Total absorbed	Second leaching	Replaceable left
1	309	13	100	94	17	0.2	−4
2	311	15	66	87	15	1.0	−1
3	374	78	404	205	37	0.5	40
4	374	78	333	192	63	2.1	13
5	428	132	760	273	97	0.6	34
6	428	132	524	206	113	2.7	16
7	506	210	888	348	172	1.0	37
8	506	210	546	299	162	1.3	47
9	651	355	1,016	363	198	1.3	156
10	651	355	497	283	132	13.9	209
11	869	573	1,073	311	163	1.0	409
12	869	573	298	241	325	56.6	191
13	1,378	1,082	1,180	263	207	2.9	872
14	1,378	1,082	0	11	9	185.0	888

After the second crop was removed, all pots were leached with rain water to obtain 2 liters of leachate on which an analysis was made to determine the amount of potassium present. Only very small quantities of potassium were leached from the odd-numbered pots, but larger quantities from the even-numbered pots. This, however, was not in proportion to the first leaching from the odd-numbered pots.

REPLACEABLE POTASSIUM REMAINING

When the absorbed and leached potassium were subtracted from the original added, there appeared to be large quantities of potassium remaining in the soil, beginning with pot 9 through pot 14. The topsoil was sampled and analyzed for replaceable potassium (Table 4). The original leached series showed very little replaceable potassium and even in the even-numbered pots only a portion of the added potassium could be accounted for. The previously leached samples were now leached with N/10 HNO_3 but very little potassium was removed; also, N/1 HNO_3 was allowed to stand on the soil overnight but very little more potassium came into solution and this was in about equal quantities all the way through the series. It was concluded, therefore, that the potassium remaining in the pot must be in the subsoil.

TABLE 4.—*Available potash in topsoil after second crop.*

Pot No.	Replaceable found*			M.E. of K per pot added	Yield of third crop		M.E. of K per pot removed by crop
	N/2 NH_4Cl and $NH_4C_2H_3O_2$	N/10 HNO_3	N/1 HNO_3		Grams of fruit	Grams dry weight	
1	6	1	1	0	0	11	1
2	4	0.4	1.6	0	0	18	2
3	7	1	2	13	91	70	20
4	7	1	2	13	62	72	27
5	8	1	2	26	83	68	27
6	8	1	1	26	42	61	33
7	9	1	2	39	0	65	47
8	10	1	2	39	46	65	42
9	10	1	2	52	14	81	58
10	13	1	2	52	378	87	73
11	8	1	2	65	322	83	73
12	78	3	2	65	90	73	80
13	8	1	2	0	166	51	20
14	369	5	2	0	27	13	22

*By leaching 50 grams of soil with 500 milliliters each treatment.

In order to see if this potassium could be returned to the topsoil, 100 rye seeds were planted and the rye allowed to grow during the summer months. Upon examination it was learned that the roots of the rye had completely permeated the topsoil but had not entered the subsoil at all (Fig. 4). It was concluded that the subsoil, being acid and carrying so little plant nutrients, had not been favorable for

root growth.[3] Upon examining the subsoil it was found that none of the roots of any of the previous crops had penetrated it.

In order to investigate the capillary action of the water in the pots on the movement of potassium, the rye was chopped up in the topsoil and a third tomato crop planted. Shortly after the crop was under way all of the plants in the odd-numbered pots began to show potassium deficiency symptoms and all but the last two of the even-numbered pots. Nitrate of potash in increasing amounts was added to the odd-numbered pots and muriate of potash and nitrate of soda (to equal the nitrogen in the nitrate of potash) were added to the even-numbered pots. The potassium-treated soils, except the high

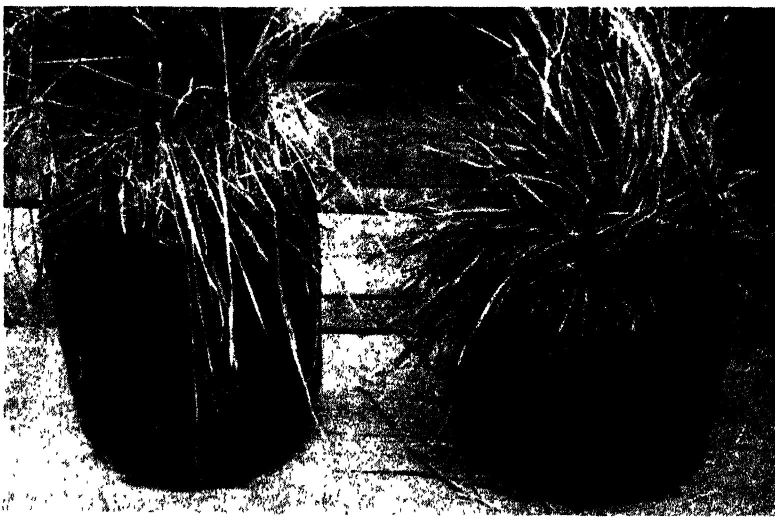

FIG. 4.—Showing that the topsoil (right) was thoroughly permeated with roots but that none had penetrated the acid subsoil (left). The two layers of soil separated when the rye was pulled upward.

salt content ones, produced good growth. The yield from this crop is shown in Table 4. These plants were analyzed for potassium and were found, except from soils of high salt concentration, to contain only the replaceable potassium found in the topsoil plus that added in fairly quantitative portions. This seems to point to the fact that if the subsoils are unfavorable for root penetration much of the potassium leached into them may be lost unless some crop tolerant to acid and unfavorable soil conditions is used to bring the potassium back. Further, since rye roots did not penetrate the subsoil in this experiment, it might be questioned whether on soils similar to this one potassium is not lost permanently unless the subsoil is limed or made more favorable for root penetration. This experiment indicates that

[3]HESTER, J. B., and SHELTON, F. A. The results of long-time fertilization and cropping practices upon the chemical and physical composition of Coastal Plain soils. Soil Sci. Soc. Amer. Proc., 2:201–205. 1937.

replaceable potassium is a good index of available potassium in Sassafras sandy loam soil and that very little weathering takes place in a period of 12 months.

PRACTICAL APPLICATIONS

In the light of this experiment it is interesting to examine field data obtained by the different methods of potash application. In a number of experiments conducted in various places it was found[4] that muriate of potash concentrated in large quantities under the row decreased the yield of tomatoes; whereas, larger quantities gave response when broadcast or used as sidedressings, as shown in Table 5. From a practical standpoint, if maximum yields are to be obtained from the use of muriate of potash, it may be advantageous to put it on sufficiently in advance of planting to permit the excessive salts to be leached from the soil or use it as sidedressings. This, of course, applies to large applications such as those often used on soil types similar to the one used in this experiment.

TABLE 5.—*Field results showing response of tomatoes to potash applied in different ways.**

Method of application	Lbs. per acre of K_2O applied	Yield, tons per acre	Lbs. per acre of K_2O absorbed by fruit
Mixed in row . . .	0	7.38	49
Mixed in row.	32	10.00	74
Mixed in row.	64	9.27	65
Mixed in row.	96	9.32	60
Mixed in row.	128	7.00	54
Broadcast.	200†	14.86	108
Sidedressed.	250†	17.01	123

*Experiment designed to make potash the limiting factor, all plats carefully replicated.
†Used to show that under some conditions method of application is a greater factor than quantity of potash used in crop production.

SUMMARY

The leaching of potassium from a 6-inch column of topsoil of Sassafras sandy loam through 6 inches of subsoil is rather small on moderate applications of muriate of potash even with very severe leaching. Potassium in the acid subsoil was not readily drawn back into the topsoil in this experiment. Replaceable potassium in a Sassafras sandy loam was a good index of available potassium to tomatoes. Potassium in the replaceable form appeared to be a more efficient source for tomatoes than muriate of potash when it was supplied in large amounts near the plant roots.

[4]HESTER, J. B. Good, fair, or poor tomatoes from your soil. Bul. 2, Agr. Res. Dept., Campbell Soup Co. 1940.

IS TRIPPING NECESSARY FOR SEED SETTING IN ALFALFA?[1]

H. M. TYSDAL[2]

IN THE literature dealing with the necessity of tripping the alfalfa flower to set seed there is no unanimity of opinion. Brink and Cooper (2)[3] and Carlson (4) state that a large percentage of flowers set seed without tripping. On the other hand, Armstrong and White (1) and Piper, *et al.* (6) state that there can be practically no seed set without tripping.

The cause of tripping is equally confusing. Certain literature would lead the reader to believe that a very large amount of automatic tripping occurs, i.e., release of the staminal column by some inner force of the flower. Other workers apparently hold that wind and rain storms or bright sunshine may cause a lot of tripping, and still others hold that insects are the major agency causing tripping. Undoubtedly some of these workers believe that a combination of the above factors, or others, have a bearing upon the sum total of tripping which takes place, but there has been no clear-cut data to show the relative importance of each. Whether it is necessary for alfalfa flowers to trip to set seed under ordinary conditions is of great practical importance both from the standpoint of investigational work and recommendations for optimum seed production.

Tripping may be defined as the release of the staminal column from the keel of the flower. The staminal column includes the style, stigma, and part of the ovary enclosed or surrounded by the 10 stamens and diadelphous filaments. This release must take place when the flower is in a turgid condition and thus it is accompanied by an explosive force as though a spring under tension is released.

During the past three years a considerable amount of work has been done in Nebraska on this subject by L. A. Clark. His work, as yet unpublished, along with other observations made by the writer, led to the study which is herein reported. The present paper presents the results of studies at the Scotts Bluff alfalfa breeding nursery and of a cooperative survey made in several of the seed-producing areas of the United States during the season of 1939.

The data given herein are reported primarily for the purpose of focusing attention on the possible importance of tripping as related to seed production in alfalfa. It is hoped the discussion will stimulate observations on this phase of the problem since, if these observations

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station, Lincoln, Nebr., as Journal Series Paper No. 251. Also presented at the annual meeting of the American Society of Agronomy held in New Orleans, La., November 24, 1939. Received for publication April 15, 1940.

[2]Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The author is greatly indebted to H. L. Westover, Senior Agronomist, Division of Forage Crops and Diseases, for suggestions and for making it possible to have cooperative observations made in several different areas of the country during the same season.

[3]Figures in parenthesis refer to "Literature Cited", p. 585.

hold true in most seed-producing areas in average seasons, it would help materially to explain some of the alfalfa seed problems encountered in recent years.

METHODS

A plan was devised under which five sets of data were obtained in each field or under each set of conditions. In each case four sets of racemes were tagged with different colored tags so they could be easily distinguished. In the first set the tripped flowers were removed from the marked racemes so that only the untripped flowers were allowed to proceed to the point where they either set pods or fell from the raceme. In the second set the flowers were allowed to develop normally and the amount of tripping that occurred was recorded. In the third group all of the flowers were tripped by hand either by introducing foreign pollen or by tripping the stigma onto its own pollen. Since there is a great difference in the percentage of pods formed, depending upon whether self or foreign pollen is used, the method employed will be indicated in each case.

The fourth group of flowers were bagged with fine nainsook muslin bags. In all of these groups the flowers which were tagged were in full bloom, untripped, and as nearly the same age as possible. Approximately 100 or more flowers were included in each set for each condition. Observations were made at sufficiently close intervals to determine whether the flower had been tripped. Since a flower which has been tripped may start wilting almost immediately, and within 2 to 4 hours have the standard petal wrapped tightly around the staminal column, it was often necessary to unwrap the standard petal to determine if tripping had actually taken place as at this stage "wilting" and "tripping" are easily confused. Ordinarily, when the observer becomes skilled in detecting tripped flowers, observations of the marked racemes morning, noon, and evening will provide accurate results.

The fifth set of observations had as their purpose the determining of the amount of automatic tripping and the amount of insect activity. This was done by continuous daylight observation of a group of flowers on one or two plants which could be kept under the eye of the observer at all times. The number of flowers which were tripped and the manner of tripping were recorded, as well as the total number of flowers visited by all insects. The total number of full flowers under observation was recorded, and the time recorded at 15- or 30-minute intervals so that later the data could be computed relative to the time of day and number of visitations per 100 flowers under observation per hour. Temperatures, weather conditions, and the amount of seed set in the field were noted.

During the summer of 1939 sets were placed on alfalfa plots or commercial fields in the following places: Ohio Agricultural Experiment Station, Columbus, Ohio; Agricultural Experiment Station, Lincoln, Nebr.; Agricultural Experiment Station, Manhattan, Kans.; Scotts Bluff Field Station, Mitchell, Nebr.; Riverton, Wyo.; Blackfoot, Idaho; Agricultural Experiment Station, Aberdeen, Idaho; Eastern Oregon Livestock Branch Experiment Station, Union, Oregon; and the Agricultural Experiment Station, Logan, Utah. The writer is indebted to T. Jackson Smith, Columbus, Ohio; C. O. Grandfield, Manhattan, Kans.; John L. Toevs, Aberdeen, Idaho; Messrs. Minnick and Perry, Union, Oregon; and J. W. Carlson, Logan, Utah, for taking the observations and for consenting to the use of their data in this paper. The interpretation of the data, however, is that of the author and does not necessarily reflect the opinions of the cooperators.

RESULTS

Table 1 gives the results of the four treatments in the different areas. The percentage of flowers tripped was found by averaging the results from the set in which the tripped flowers were removed, together with the results from the set in which the flowers were allowed to develop normally but in which a record was kept of the amount of tripping. Three divisions are made in Table 1 according to the estimated seed-yielding capacity of the fields under observation. For example, three fields were chosen within a few miles of each other near Riverton, Wyo., one of them setting seed very well (estimated at 500 pounds per acre, subsequently found to yield 560 pounds per acre); a second which was intermediate in seed production, estimated at 250 pounds per acre; and a third which was setting very little seed, estimated at approximately 60 pounds per acre. Thus, in this area, is represented a poor, medium, and good field. The fields are numbered in Table 1 for identification purposes.

TABLE 1.—*Percentage of flowers naturally tripped in different areas of the country and percentage forming pods under four different treatments.*

Place	Station or farm No.	Percentage flowers tripped naturally	Percentage flowers forming pods			
			Without tripping	Naturally	Artificially tripped	Under bags
Fields with Poor Seed Setting						
Ohio	1	38	2	20	67	5
Nebraska	2	37	3	24	27*	3
Wyoming	5	33	6	23	76	4
Idaho	8	14	2	7	91	4
Idaho	9	36	0	5	77	1
Oregon	11	11	2	14	58	1
Utah	13	25	2	12	75	3
Av.	—	28	2	15	74	3
Fields with Medium Seed Setting						
Nebraska	3	19	1	10	89	5
Kansas	4	44	1	24	41*	4
Wyoming	6	33	6	20	81	3
Av.	—	32	3	18	85	4
Fields with Good Seed Setting						
Wyoming	7	63	0	47	73	1
Idaho	10	44	0	25	73	5
Oregon	12	41	0	33	81	1
Av.	—	49	0	35	76	2

*Self-pollinated, not used in averages; all others were cross-pollinated.

The average percentage of the flowers tripped by natural causes, whether by wind, insects, or automatically, shows a rather wide variation in different fields whether they are good or poor, but in

general the poor fields have less tripping than the medium or good fields. The differences have not been statistically analyzed, but it is clear from the data, and still clearer from field observations, that the poor fields did not have the large amount of tripping that was found in the good fields. A correlation of $.8167 \pm .0623$ was found between percentage of flowers tripped under natural conditions and percentage of flowers forming pods under natural conditions, although some variation between different fields is evident.

Columns 4 and 7 in Table 1 show that under average conditions tripping is necessary for seed setting. Thus, although tripping may not insure seed production, at least seed will not be produced to any great extent without tripping. All the fields under observation, involving some seven different widely scattered areas in the United States, and a large number of observations for each condition, present no single exception to a very low percentage of pod set when the tripped flowers are removed. The highest percentage found was 6 and in most cases it was less.

Column 7 in Table 1 shows the percentage of flowers forming pods when the full untripped flowers were enclosed in nainsook muslin bags. Obviously no large insects visit the flowers so enclosed. The percentage of the flowers forming pods under these conditions checks very closely with the amount of pod setting when the tripped flowers are removed as shown in column 4. To determine whether the muslin bag disturbed seed setting, a test was run where all of the flowers enclosed in the bag were artifically tripped before covering, a group of racemes from the same plant were enclosed in other bags in the usual manner at the same time, and a third group was artifically tripped and left to develop without being covered. It was found that 3.6% of the flowers which were enclosed in the bag but not tripped developed pods, 85.7% of the flowers which were enclosed in the bag but tripped before covering produced pods, and 78.5% of the flowers which were artificially tripped and allowed to develop on the outside produced pods. This indicated that the bag in itself apparently did not have a harmful effect on pod setting.

Column 5 in Table 1 gives the average percentage of flowers forming pods under natural conditions. The good fields averaged considerably higher in this respect than the poor or medium good fields. It should be pointed out that these data are relative rather than exact for any given field, the chief reason being that when the racemes were tagged and visited rather frequently by the observer less insect activity occurred on the plants under observation. For example, actual counts were made in fields 2, 8, and 10 on the number of flowers producing pods in the field as a whole at about the time the sets were being observed. This was done by taking a representative group of racemes on which the pods were about the same age as those on the observed plants, and counting by the bracts the number of flowers originally on the racemes and then counting the number of pods actually set. When this was done, it was found that in field 2 actually 44% of the flowers set pods compared to 24% reported in Table 1; that in field 8, 10% of the flowers had set pods, whereas Table 1 indicates 7%; while in field 10, 54% of the flowers were setting pods,

compared to 25% as found on the plants under observation. The same explanation may be given for the observations on the actual amount of tripping occurring in the field and the amount found on the plants under observation as given in column 3. Thus, the general observations in the field, taken very carefully, are important in the final interpretation.

The results to which this explanation does not apply are those in which the condition of the flower was determined by controlled means, as in the case of the percentage of flowers forming pods without tripping and those which were artificially tripped, and perhaps to a lesser extent those enclosed within the bag. The results of these three treatments are also much less variable than the others just mentioned.

The results from artificial tripping are of particular interest. In this experiment a group of racemes was used on the same plants on which the other observations were being made, all the flowers being tripped by hand, and usually cross-pollinated by gathering foreign pollen on a toothpick and then tripping the flower with this toothpick in such a way that the stigma snapped onto the foreign pollen. No attempt was made to remove the flower's own pollen, which was also present, but previous experiments had indicated that the foreign pollen is the effective agent from 80 to 98% of the time. When no foreign pollen was introduced the flowers were said to have been self-pollinated, although a few stray pollen grains may have adhered to the standard or other parts of the flower.

With two exceptions, the results reported for artificial tripping in Table 1 are from cross-pollinations. In practically all cases, whether in Ohio or Oregon, the alfalfa set a very high percentage of pods when cross-pollinated. When it is considered that if 50% of the pods set seed in the ordinary alfalfa field a good crop of seed is obtained, the high percentage of setting with artificial tripping can readily be appreciated. The averages for the poor, medium, and good fields do not show any significant trends, as they are all quite high.

The two exceptions, those which were self-pollinated in Nebraska and Kansas, show a very much lower percentage forming pods. That this may be considered a general condition in alfalfa is shown by the results given in Table 2.

In the first part of Table 2 is given the average percentage of pods set for a number of representative plants when selfed and cross-pollinated. In all tests the percentage of flowers forming pods for the selfed material is much lower than that for the crossed. On the average 92% more pods are set from the crossed than from the selfed flowers.

The second part of Table 2 gives the results of a similar experiment on different individual plants. Plant 16–42 set almost as many pods when self-pollinated as when cross-pollinated; plant 31–43, on the other hand, was almost self-sterile, setting only 10% of pods as compared to 97% when cross-pollinated. A sufficiently complete sampling of the population has not been made to estimate what proportion of the average commercial alfalfa population is largely self-fertile. Observations during the course of the breeding program, however, would indicate that relatively few plants are as self-sterile as No.

TABLE 2.—*Percentage of flowers forming pods when all flowers are tripped and self-pollinated compared to all flowers tripped and cross-pollinated.*

Place	Percentage of flowers forming pods	
	Selfed	Crossed
Average of Several Plants		
Ohio	32	67
Nebraska, 1938	16	50
Nebraska, 1939	60	89
Av.	36	69
%	100	192
Variability of Individual Plants		
Nebraska, 1939:		
Plant No. 16–46	93	100
31–41	70	100
20–51	58	97
31–43	10	97

31–43, but many indications (3) point to a selective fertilization in practically all plants if the foreign pollen is available.

In addition to the higher percentage of pods being formed upon cross-pollination, data presented in Table 3 indicate that a larger number of seeds are formed per pod from the cross-pollinated than from the self-pollinated flowers. As an average of three separate readings, one at Ohio and two at the Scotts Bluff alfalfa breeding nursery, one in 1938 and the other in 1939, the pods produced from self-pollination contained 2.44 seeds each, while those from the cross-pollination contained 3.80 seeds each, an increase of 56%. Considering both the percentage of flowers forming pods and the number of seeds per pod, the cross-pollinated flowers produced almost exactly three times as much seed as the self-pollinated.

An important consideration from the standpoint of principles involved, is the variability in seed setting during different parts of the

TABLE 3.—*Number of seeds per pod when self-pollinated as compared to seeds from cross-pollinated flowers.*

Place	Number of seeds per pod	
	Selfed	Crossed
Columbus, Ohio, 1939	2.15	2.81
Scotts Bluff, Nebr., 1938	2.00	2.47
Scotts Bluff, Nebr., 1939	3.16	6.11
Av.	2.44	3.80
%	100	156

same season. Table 4 gives the amount of natural tripping taking place at different times in the same season at Columbus, Ohio, and at Scotts Bluff, Nebr., and also the percentage of flowers forming pods during the same period. It is evident that during a short period of one or two weeks a very great difference in response is obtained. At Scotts Bluff, in a set on August 8, no tripping was found on the plants under observation nor were any pods set. In a set on August 21, however, 61% of the flowers were naturally tripped and 28% of them set pods. The first three days after the set of August 8 the mean maximum temperature was 71° F and the mean minimum 50°. The mean maximum relative humidity was 98% and the mean minimum 44%. Similar figures for the 3-day period following the set of August 21 were mean maximum 89° F, mean minimum 53°, mean maximum relative humidity 98%, and mean minimum 22%. Field observations often show as much variability from day to day as shown in Table 4

TABLE 4.—*Variability in percentage of flowers tripped and percentage forming pods under natural conditions at different times of the season.*

Place	Date	Percentage flowers	
		Tripping	Forming pods
Columbus, Ohio.	Aug. 1–15	25	16
	Sept. 6–20	64	30
Scotts Bluff, Nebr.	July 27	13	7
	Aug. 8	0	0
	Aug. 21	61	28

from week to week. In fact it has been one of the interesting results to observe how remarkably sensitive bees, and particularly *Megachile*, are to weather conditions. When the weather was at all cold or cloudy or rainy a very sudden drop or complete cessation of insect activity was noted. This may be one of the keys explaining why alfalfa seed setting is so sensitive to weather conditions. Table 4 again gives an indication of the close relation between tripping and pod setting, the rank in percentage of tripping being the same as the rank in percentage of flowers forming pods.

Time and temperature records were taken when continuous observations were made on insect visitation to alfalfa flowers at Scotts Bluff in 1938 and Lincoln in 1939. The total number of flowers visited and the total number of flowers tripped were recorded, as well as the approximate number of flowers under observation. These records are tabulated on the basis of time of day and temperature in Table 5. Table 6 gives the comparable data for one day, August 24, 1938. Table 6 also gives the visitations to alfalfa flowers by the *Megachile* species as distinguished from the total number of flowers visited by all insects.

In all tables the averages are in terms of number of flowers visited or tripped per hour per hundred flowers under observation. This will be referred to as "percentage" of flowers visited or tripped per hour,

TABLE 5.—*Number of insect visitations to a known number of alfalfa flowers and number of alfalfa flowers tripped at different times of the day and at different temperatures, Scotts Bluff, Nebr., Aug. 24 to Sept. 6, 1938.**

Time of day and temperature	Total No. flowers visited	Percentage of flowers visited per hour	Total No. flowers tripped	Percentage of flowers tripped per hour
8– 9 a.m.	72	4.8	6	0.4
9–10 a.m.	67	4.5	28	1.9
10–11 a.m.	160	10.7	30	2.1
11–12 a.m.	82	5.5	31	2.1
12– 1 p.m.	97	6.7	49	3.3
1– 2 p.m.	353	23.6	67	4.5
2– 3 p.m.	430	28.7	81	5.4
3– 4 p.m.	462	30.8	84	5.7
4– 5 p.m.	100	6.7	0	0.0
70° F	355	9.6	50	0.9
75° F	1,426	15.9	149	1.7
80° F	1,658	18.6	358	5.1
85° F	2,897	34.3	649	7.4

*The results are averages for a 7-day period.

TABLE 6.—*Number of insect visitations to a known number of alfalfa flowers and number of alfalfa flowers tripped at different times of the day and at different temperatures, Scotts Bluff, Nebr., Aug. 24, 1938.*

Time of day	Total No. of flowers visited	Percentage of flowers visited per hour	Total No. of flowers tripped	Percentage of flowers tripped per hour	Percentage of flowers visited by *Megachile* per hour	Temperature, ° F
8– 9 a.m.	72	4.8	6	0.4	0.7	68°
9–10 a.m.	67	4.5	28	1.9	2.0	72°
10–11 a.m.	108	7.2	28	1.9	2.0	75°
11–12 a.m.	82	5.5	31	2.1	2.3	75°
12– 1 p.m.	97	6.7	49	3.3	3.8	80°
1– 2 p.m.	238	15.8	134	8.9	11.1	81°
2– 3 p.m.	251	16.7	106	7.1	8.8	82°
3– 4 p.m.	264	17.6	78	5.2	6.4	83°
4– 5 p.m.	12	0.8	0	0.0	0.0	82°

as the case may be, but it should be understood that it is calculated on the basis of the number of full flowers remaining untripped each hour. Thus, both time and number of flowers are kept constant, making it possible to compare from day to day and at different temperatures. There were actually about 1,500 flowers under observation during this test.

The data for the one day, August 24, which is taken because complete records were made from morning to evening and because it shows several typical tendencies, are graphically presented in Fig. 1. This figure shows the total insect visitations, *Megachile* visitations, and the number of flowers tripped at different periods of the day, reported in per cent. The notes made in the record book indicate that the

morning was rather cloudy but that the sun came out bright and warm just before 1:00 o'clock and remained out during the afternoon. The insect activity as represented by the number of flowers visited per hundred per hour shows a very decided increase during the 1:00 to 2:00 o'clock period as compared with the 12:00 to 1:00 o'clock period. Similarly, the activity of the *Megachile* species shows an increase at this time of day. As can be noted from the graph, the amount of tripping also increased very much at this time. Perhaps the most important feature of the graph is the very close correlation between the *Megachile* visitation and the number of flowers tripped. If, as has been indicated, the *Megachile* species is the most important in causing tripping in this section, it is to be expected that there would be a close correlation between *Megachile* activity and tripping.

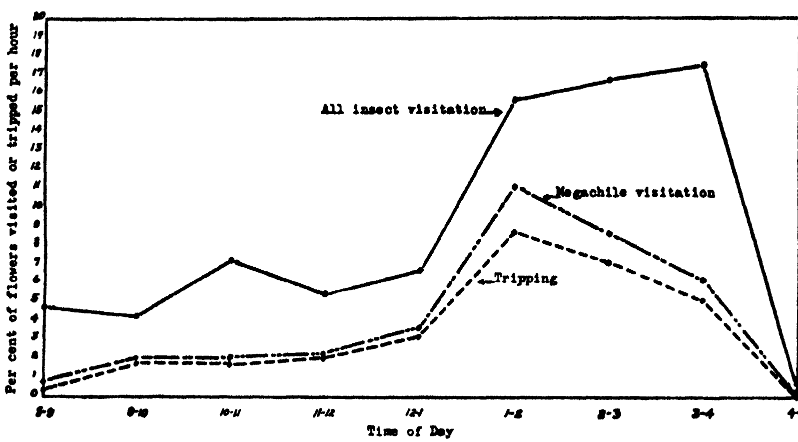

FIG. 1.—Tripping and insect visitation as related to time of day, Scotts Bluff, Nebr., Aug. 24, 1938.

It will also be observed that the insect activity is greatest during the middle of the afternoon, and it is also during this period, from 1:00 to 4:00 o'clock, that the greatest number of flowers are tripped. As a rule there is very little *Megachile* activity in the late afternoon, and this is correlated with practically no tripping from about 4:00 o'clock in the afternoon to 8:00 o'clock the next morning during this season in western Nebraska. In Lincoln, however, there is some continued activity from 4:00 to 5:00 o'clock in the afternoon.

Temperatures apparently play a very important role in insect activity and alfalfa tripping, as shown in Tables 5 and 6 and in Fig. 2. In western Nebraska the insect activity and number of flowers tripped increased with each successive 5° raise in temperature from 70° to 85° F, showing that the warmer the day, the greater the tripping. Evidently the threshold value for beneficial insect activity is in the neighborhood of 65° F under these conditions, although this might vary somewhat with species and with environmental conditions.

In 1939 observations were made at Lincoln on insect visitations to alfalfa flowers and tripping. Table 7 gives the result of observations taken at intervals during the period of August 18 to 22, 1939, and Table 8 gives the results of continuous observations made on total tripping occurring in the field during the period of September 7 to 15, 1939. During the latter period, very great activity of insects was recorded and a very high percentage of tripping noted. Over 85% of all flowers under observation during this period were tripped. As can be seen from Table 8, there is again a correlation between the amount of tripping and temperature, there being a gradual increase in the number of flowers tripped per hundred per hour from 70° to 100° F. In the Lincoln data for the period of August 18 to 22, a drop in the insect activity and tripping is noted at 85° F. This is attributed to inconsistency of the data, rather than an actual decrease in activity at this temperature.

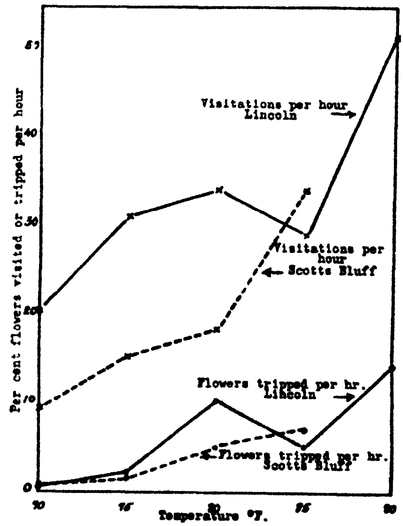

FIG. 2 —Tripping and insect visitation to alfalfa flowers as related to temperature, Scotts Bluff, Nebr., Aug. 24 to Sept. 6, 1938, and Lincoln, Nebr., Aug. 18 to 22, 1939.

Table 8 also shows the greatest amount of tripping to be during the period of 1:00 to 4:00 p.m., although a considerable amount of tripping occurred earlier in the day during the warm period. The relationship between insect visitation and tripping may of course be entirely altered according to the insect population present. For example, in counts where there was a high honey bee population there was as high as 90% of the flowers visited per hour but there was less than 2% of the flowers tripped.

TABLE 7.—*Number of insect visitations to a known number of alfalfa flowers and number of alfalfa flowers tripped at different temperatures, Lincoln, Nebr., Aug. 18–22, 1939.*

Temperature, ° F	Total No. of flowers visited	Percentage of flowers visited per hour	Total No. of flowers tripped	Percentage of flowers tripped per hour
70°	154	20.5	4	0.5
75°	233	31.2	15	2.1
80°	257	34.3	79	10.5
85°	348	29.5	66	5.3
90°	390	51.9	107	14.3

The question, therefore, of what causes tripping in alfalfa may be answered, at least for certain field conditions, although these results do not preclude the possibility of automatic tripping taking place

TABLE 8.—*Total number of alfalfa flowers tripped during continuous daytime observations of marked racemes at different times of the day and at different temperatures, Lincoln, Nebr., Sept. 7–15, 1939.*

Time of day and temperature	Total No. flowers tripped	Per cent flowers tripped per hour
8– 9 a.m.	6	11.4
9–10 a.m.	10	12.9
10–11 a.m.	8	11.3
11–12 a.m.	16	14.6
12– 1 p.m.	12	18.2
1– 2 p.m.	17	25.5
2– 3 p.m.	16	30.0
3– 4 p.m.	11	35.8
4– 5 p.m.	4	13.4
70° F	19	6.9
75° F	23	17.2
80° F	52	17.9
85° F	79	21.5
90° F	94	18.9
95° F	243	19.1
100° F	144	37.1

under different conditions. Many of these results have been obtained by tagging certain racemes, which were closely and continuously observed during the daylight hours for any change that might occur. This is more difficult to do than may appear, however, as it is difficult to observe each flower, particularly during windy weather. The writer can say from experience that it is almost impossible to detect all of the insect activity actually in progress when a high wind is vigorously waving the 8 or 10 marked racemes of a plant. It is believed that for this reason a considerable amount of insect activity has been overlooked in the past. It is also believed that this may account for the unusually high reading for automatic tripping recorded at Lincoln in Table 9. The readings at Lincoln were made in very unusual weather. The maximum temperature during the period reached 105° F and the average maximum from September 6 to September 14, during which time readings were made, was 95° F. The average maximum wind velocity for the same period was 23 miles per hour, the highest velocity being 28 miles, and the lowest 16 miles. Twenty-six hundredths of an inch of rain had fallen in the preceding 3-week period, and previous to that time precipitation was scanty. Thus very dry, hot, windy conditions pervailed, which, according to some observers, would be ideal for seed setting provided there was sufficient moisture to allow continued development of the plant. Since the plants under observation were space-planted, sufficient moisture was present to allow them to continue growth. As a matter of fact these conditions apparently were beneficial for seed production because some of the plants which were left for seed produced a good seed crop, many of them at the rate of about 10 bushels per acre.

In making the observations it was considered desirable to allow the plants as much freedom as would obtain under natural conditions.

Approximately 10 racemes were tagged on each plant and a note made as to the number of full flowers on each raceme. The wilted, tripped, or undeveloped flowers were removed, records being made of each insect visitation, each time the insect tripped a flower, or each time a flower was tripped without the aid of an insect. The latter tripping might have been caused by brushing against other stems blown by the wind, or by the opening of the keel due to dehydration or high temperatures. It has been demonstrated under experimental conditions that high temperatures of about 140° to 150° F will cause automatic tripping, and that the addition of a very small drop of alcohol to the clasp of the keel will cause it to open. Regardless of the manner in which the tripping occurred, when not due to insects, it was listed in Table 9 as automatic.

TABLE 9.—*Cause of tripping of alfalfa flowers as determined by field observations of marked racemes.*

Place	No. of flowers under observation	Percentage of flowers tripped		
		By insects	Unknown	Automatically
Nebr. (Lincoln)	739	44	12	29
Nebr. (Scotts Bluff)...	260	26	8	1
Wyoming	55	22	0	0
Idaho............	95	4	0	2

One other statement should be made relative to the data from Lincoln. In one test, the stems having marked racemes were tied to stakes so that they could not be blown by the wind, thus permitting careful and continuous observation of the flowers. Not a single flower tripped automatically all day. The data from Lincoln are therefore included in Table 9 with reservations, but despite all of these considerations it is believed they are of some value to show that even under these unusual conditions the amount of automatic tripping recorded is not sufficient to produce a good seed crop.

The data from Scotts Bluff, Nebr., Wyoming, and Idaho are consistent in showing very little or no automatic tripping, even under conditions which in Wyoming produced 560 pounds of seed per acre. The actual percentage of tripping indicated in Table 9 is relative but not truly indicative of the tripping in the general field, as again it was taken when the observer was immediately adjacent to the plant and it was very evident that the wild bees did not work as well under close observation as on plants farther away.

Table 10 gives a brief summary of the actual agencies causing tripping.[4] By far the largest number of visitations to alfalfa flowers in most seed-producing areas are by honey bees (*Apis* sp.). The leaf cutter bees, often called ground bees or solitary bees, all of which are species of *Megachile*, probably are second in number in Nebraska,

[4]Acknowledgment is made to Prof. Don B. Whelan of the Department of Entomology, University of Nebraska, for kindly making the identification of insects observed working on alfalfa.

and other insects, such as bumble bees, wasps, etc., are present in smaller numbers. In the western states, including Wyoming, Idaho, and possibly Utah and Oregon, the alkali bees or ground bees, which are species of *Nomia*, chiefly *Nomia melandri*, appear to be the most common alfalfa pollinators. In eastern states bumble bees appear to be more important.

TABLE 10.—*Amount of tripping of alfalfa flowers caused by various insects as determined by field observations of marked plants.*

Place and year	No. of flowers visited by			Percentage of flowers tripped by		
	Honey bee	*Megachile* and *Nomia* sp.	Misc. insects	Honey bee	*Megachile* and *Nomia* sp.	Misc. insects
Ohio, 1939	1,401	79	30	2.7	94	87
Nebr., 1938	3,442	635	331	0.3	83	11
Nebr., 1939	528	45	325	0.6	91	6
Wyoming, 1939	1,282	39	0	1.7	82	0
Total or av	6,653	798	686	1.1	84	12
Total No. of flowers tripped	—	—	—	76	674	82

In these tests the honey bee was not an effective tripper of alfalfa flowers. Out of 6,653 alfalfa flowers visited by honey bees, a total of 76 or 1.1% were tripped. On the other hand, during the same period 798 flowers were visited by leaf cutter bees and 674 or 84% were tripped. A total of 686 flowers were visited by a number of other insects, including bumble bees (*Bombus* sp.), wasps, moths, and others, and of these 82 or 12% were tripped. Most of these were tripped by bumble bees, which apparently, however, vary in effectiveness, tripping from 38 to 80% of the flowers visited. During these observations the *Megachile* or *Nomia* sp., which are remarkably adapted for producing cross-pollination in alfalfa, tripped more than four times as many flowers as all the rest of the insects combined.

One factor which is not clearly brought out in Table 9 is the effect of constant visits of honey bees to the same flower. When the bees are extremely numerous the same flower may be visited a great many times, and in this way a higher percentage of flowers are tripped than shown in Table 10. Actual counts have shown honey bees to trip as much as 12% of the flowers of a given raceme during the course of two or three days. This would indicate that honey bees in abundance might be beneficial for seed setting. It has also been observed that certain honey bees are much more apt to trip alfalfa flowers than others, thus indicating rather wide differences among individuals in the same species. Plants also differ in ease of tripping.

The possibility of antagonism or competition between various insects should perhaps be given consideration in future investigations. Thus, for example, an abundance of honey bees might tend to dis-

courage the activity of the *Megachile* or *Nomia* sp. which might otherwise be present. Whether there is any such competition is not known, but even if there is no direct antagonism, it is evident that if one species is present in such abundance that it tends to rob the nectar from another more beneficial species it would be to the disadvantage of the seed grower.

DISCUSSION

The most effective pollinators in this study have been the *Megachile* and *Nomia* bees, several species of which have been observed working on alfalfa. Other conditions being favorable, it would appear that one of the most effective means of insuring a seed crop of alfalfa would be a supply of these small, relatively harmless, hard-working insects. It should, therefore, be sound agronomic practice to encourage their presence in an alfalfa seed field. The writer has talked with alfalfa seed growers who have plowed through a large colony of these bees, which often make their home in the ground, and in some instances it has been known that such practices have destroyed the entire colony, or at least caused it to move. It would seem to be worth while to investigate the possibilities of propagating such bees which are effective tripping agents. The presence or absence of tripping insects in an alfalfa field may eventually prove to be a reliable criterion of seed setting possibilities, providing their sensitivity to weather conditions is also taken into consideration.

The results presented in this paper point to the conclusion that, in general, alfalfa flowers must be tripped to produce seed, and that ordinarily there is not sufficient automatic tripping to produce satisfactory seed crops. It would not be true to say that all seed conditions have been encountered in these investigations, and thus it is possible that under certain conditions a higher percentage of flowers might produce seed without tripping, or a higher percentage of automatic tripping might occur than was observed; however, it would seem that such conditions are comparatively rare. Strengthening this conclusion is the fact that all reports in the literature indicate a high percentage of natural crossing in alfalfa, and our own results show from 60 to 90% natural crossing under Scotts Bluff conditions, and crossing would appear to be difficult to explain without tripping. Sudden rain storms which have been observed to cause considerable tripping would not appear to be advantageous for cross pollination.

It should be noted that autogamous plants have been found in certain breeding programs. Kirk and White (5) have reported such results and at least one plant which sets seed without tripping has been isolated in the Nebraska alfalfa breeding program. Some of these plants apparently set seed without tripping or are self-tripping. While these possibilities should be thoroughly investigated, it is difficult to see how continued vigor of growth could be maintained if the plants were entirely self-fertilized. It may be possible, however, to combine a certain amount of self-fertility with sufficient natural crossing to increase the general seed setting of the strain.

Tripping by mechanical means does not at present appear to be feasible for two chief reasons. In the first place, new alfalfa flowers

are developing all the time, since alfalfa has an indeterminant inflorescence, and they are in prime condition for fertilization only from one to three days. To trip them at the right time would necessitate going over the field a large number of times. In the second place, unless the machine were constructed so that a large amount of crossing occurred, and this would seem difficult to accomplish, the self-fertilization resulting from such tripping would cause less seed per flower and lower vigor of growth of the resulting progeny than would result if the same flowers were cross-pollinated.

A rather significant situation appears when the alfalfa seed areas are studied from the standpoint of reliability in seed production. It appears that the most consistent seed production has been in the pioneer areas. Some areas were good seed producers and then, without apparent reason, seed failures became common, although in occasional years a good seed crop was obtained (4). On the other hand, during these same years, new areas brought under production produced rather consistently good seed crops. Examples of these newer areas are found in isolated districts of western Utah, in Oregon, and in the newly developed irrigation project at Riverton, Wyoming. The author can state that he saw more colonies of the *Nomia* species in the Wyoming areas than in any other seed production area he has visited.

Entomologists who have observed the alfalfa pollinating insect population in Nebraska for many years unhesitatingly state that there are fewer colonies of *Nomia* species and fewer of *Megachile* species than formerly. It is possible that cultivation and settlement has disturbed the wild bees and thus reduced their number. Hence, it is suggested that a decrease in the population of these beneficial insects, together with a possible increase in harmful insects, may be an explanation for the uncertainty in alfalfa seed production in formerly good seed-producing areas.

One criticism made of the dependence upon insects for seed setting in alfalfa is that in certain years very good seed production is obtained in areas which have not been producing good seed crops. This cannot be explained from the data at hand, but reference can be made to very great differences in seed setting of red clover from year to year in which crop it has been admitted insect visitation is a necessity. Observations have indicated a great difference in the beneficial insect population in a given area from year to year. Apparently, favorable or unfavorable environmental conditions can cause a very rapid change in the insect population.

Despite emphasis placed on tripping, it should be remembered that many other factors affect alfalfa seed production. It is only too true that under some conditions all the flowers could be tripped and cross-pollinated and still set very little seed. Under other conditions, such as stimulation of the vegetative phase of growth as compared to the reproductive phase, or presence of harmful insects, such as *Lygus*, very few flowers may be produced. Apparently the balance which is necessary for reproductive development in alfalfa can very easily be tipped toward the vegetative phase and no doubt that is why alfalfa is such a high forage producer. There are many examples, however, in seed-producing areas where everything seems to be

favorable for a seed crop and yet the crop is very poor. Under these conditions a lack of tripping may be the determining factor.

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THE NITROGEN, ORGANIC CARBON, AND pH OF SOME SOUTHEASTERN COASTAL PLAIN SOILS AS INFLUENCED BY GREEN-MANURE CROPS[1]

RULON D. LEWIS AND JAMES H. HUNTER[2]

THE status of the nitrogen and carbon in the soil involving both actual content and ratio has been recognized as correlated with crop productivity. Both these constituents are normally low in the soils of the southeastern United States. According to the work of Jenny (3)[3], this is the result of the prevailing climatic conditons. This being true, it is important to know what level of nitrogen and carbon content is necessary in these soils to insure satisfactory crop production.

Albrecht (2) recognized the difficulties of raising the level of nitrogen and carbon in the soil under southern conditions and pointed out that it might even be impossible to build these up to the level of virgin soil. For many years southern leaders in agriculture have stressed the use of legumes as a means of maintaining crop production.

Many data are available indicating the value of legumes in maintaining yields, but there is a scarcity of data showing that nitrogen or carbon are increased to any appreciable extent over a period of years. It is the purpose of this paper to present data on the nitrogen and carbon content of three important Coastal Plain soils, under different green-manuring systems and management in order that some light may be shed on the economy of using legumes for the maintenance of crop production on these soils.

EXPERIMENTS ON GREENVILLE AND NORFOLK SANDY LOAMS

PLAN AND PROCEDURE

In these experiments varying amounts of vegetation from different crops were grown and returned to the soil for the purpose of making a study of their influence on the carbon and nitrogen relationships in the soil. The crop management systems used are ones which can be used in pecan and other orchards of the southeastern states. Details of the cropping systems and crops are given in Table 1. All the material grown under the various cropping systems was returned to the soil except in system H in which the ear corn and the seed cotton were removed. System A involved cultivation often enough during the summer to keep down the weeds and grass. All other systems involved sufficient cultivation to insure good crop growth. A 4–8–4 fertilizer[4] was applied at the rate of 400 pounds per acre annually to

[1]Contribution from the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, Albany, Georgia. Credit is due Dr. J. J. Skinner of the Bureau of Plant Industry, U. S. Dept. of Agriculture, in charge of soil fertility studies in the southeastern states, for guidance in developing these investigations. Received for publication April 27, 1940.

[2]Associate and Assistant Soil Technologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 601.

[4]The fertilizer constituents are given in the order of nitrogen, phosphoric acid, and potash. The fertilizer was non-acid forming.

all systems except system E which received no fertilizer. Representative portions of the crops were harvested to get approximate yields of the above-ground growth just previous to turning in the crops, or at such time as seemed best to record the maximum production of green manure. Hereafter in this report the cropping systems will be referred to by the designated symbols, as A, B, C, etc., as given in Table 1.

Greenville and Norfolk sandy loam soils in the vicinity of Albany, Georgia, were used in this study.[5] Both soils are well drained. The A horizon of the Greenville soil is about 6 inches deep, is brownish red in color, while the B horizon is red and has undergone considerable illuviation. The A horizon of the Norfolk is about 8 inches deep and is light gray in color; the yellow B horizon does not contain as much colloidal material as the corresponding layer of the Greenville soil.

The mean annual rainfall for Albany, Georgia, is approximately 50 inches and the mean annual temperature about 69° F.

The Greenville soil was in peanuts the year preceding the experiment while the Norfolk soil grew native weeds and grass. No commercial fertilizer had been applied for a number of years.

Composite soil samples were taken from the A horizon of both soils at the beginning of the experiments and in December each year thereafter. The official A. O. A. C. method was used for nitrogen, the wet oxidation method of Adams (1) for carbon and the hydrogen electrode for the pH.

EXPERIMENTAL DATA

The yields are given as pounds of green weight per acre in Table 2 for the Greenville soil and in Table 3 for the Norfolk soil. The yields as an average for 4 years vary in the above-ground parts from 2,548 pounds per acre annually up to 41,034 pounds. There is a close similarity in the yields of the crops in the different systems on the two soils (4).

The data on the nitrogen and carbon contents for the Greenville soil are given in Table 4 and shown graphically in Fig. 1. It is evident that the nitrogen has been increased materially under all systems, and in most cases it has been doubled the original amount in the soil. The carbon has not increased so consistently. In all the systems except the two permanent cover crops, F and G, the carbon has dropped below the original level at least one year, but when the average for the period is compared with the original carbon content there are gains in all systems. Due to large increases in nitrogen as compared to the carbon the carbon-nitrogen ratio has been narrowed materially. In the cropping systems, the highest level of nitrogen occurred where the largest amounts of materials have been turned into the soil, systems B and D. Although there is some relationship between the amount of material returned to the soil and the accumulation of

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[5]W. M. Van Cise and R. H. Waugh, pecan growers of the Albany, Georgia, section, contributed land and labor for these experiments. Their cooperation is appreciated. These experiments were inaugurated by E. D. Fowler, formerly of the Bureau of Plant Industry, now with the Soil Conservation Service, U. S. Dept. of Agriculture.

TABLE 1.—*Details of cropping systems used in the study of carbon and nitrogen relationships in Greenville and Norfolk sandy loam soils, Albany, Georgia.*

Type of cropping system*	1935		1936		1937		1938	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
A, Winter green manure	Austrian peas, vetch, and rye		Vetch and rye		Rye		Austrian peas, vetch, and rye	
B, Winter and summer green manure (largely legumes)	Austrian peas, vetch, and rye	Velvet beans	Vetch and rye	Cowpeas	Rye	Runner peanuts	Austrian peas, vetch, and rye	Velvet beans
C, Summer green manure		Velvet beans		Cowpeas		Runner peanuts		Velvet beans
D, Winter cereal and summer legume	Rye	Crotalaria	Oats	Crotalaria	Rye	Crotalaria	Rye	Crotalaria
E, Winter cereal and summer legume (not fertilized)	Rye	Crotalaria	Oats	Crotalaria	Rye	Crotalaria	Rye	Crotalaria
F, Kudzu permanent cover		Kudzu		Kudzu		Kudzu		Kudzu
G, Bermuda grass sod		Bermuda grass		Bermuda grass		Bermuda grass		Bermuda grass
H, Cash crop rotation with summer legumes		Corn and velvet beans		Cotton		Runner peanuts		Corn and velvet beans

*A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.

TABLE 2.—*Effect of different cropping systems on yield in pounds per acre of green-manure crops on Greenville sandy loam, Albany, Georgia.*

Type of cropping system*	1935		1936		1937		1938		Average annual green weight, lbs.
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
A, Winter green manure	4,486	—	9,801	—	2,831	—	13,634	—	7,688
B, Winter and summer green manure (largely legumes)	6,316	16,770	13,504	7,971	12,415	25,482	15,028	20,038	29,381
C, Summer green manure	—	13,504	—	4,051	—	24,394	—	14,375	14,081
D, Winter cereal and summer legume	4,008	28,532	6,098	21,649	11,631	29,839	9,714	16,988	32,115
E, Winter cereal and summer legume (not fertilized)	2,091	12,850	2,396	8,799	1,089	10,934	1,307	7,318	11,696
F, Kudzu permanent cover	—	6,752	—	9,583	—	14,810	—	13,721	11,217
G, Bermuda grass sod	—	7,187	—	8,095	—	7,667	—	4,792	6,926
H, Cash crop rotation with summer legumes	—	16,770	—	—	—	20,691	—	5,009	14,157†

*A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.
†Three-year average; yield of cotton stalks in 1936 not taken.

TABLE 3.—*Effect of different cropping systems on yield in pounds per acre of green-manure crops on Norfolk sandy loam, Albany, Georgia.*

Type of cropping system*	1935		1936		1937		1938		Average annual green weight, lbs.
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
A, Winter green manure	2,962	——	9,365	——	5,009	——	18,730	——	9,017
B, Winter and summer green manure (largely legumes)	3,398	13,504	12,632	7,710	11,543	23,305	17,424	15,246	26,190
C, Summer green manure	——	10,237	——	6,970	——	22,216	——	17,642	14,266
D Winter cereal and summer legume	3,333	25,483	8,843	39,552	13,504	36,373	17,250	20,909	41,034
E, Winter cereal and summer legume (not fertilized)	828	5,772	697	3,833	1,089	3,398	131	——	3,937
F, Kudzu permanent cover	——	5,336	——	8,538	——	12,415	——	14,810	10,275
G, Bermuda grass sod	——	871	——	4,225	——	——	——	——	2,548†
H, Cash crop rotation with summer legumes	——	10,563	——	——	——	20,691	——	6,839	12,698‡

*A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.
†Two-year average. The growth on this plat was largely native grasses and broom sedge after 1936. These were cut at intervals during the year and allowed to emain on the soil but no record of yield was taken.
‡Three-year average; yield of cotton stalks not taken in 1936.

TABLE 4.—*Content of organic carbon and total nitrogen, also carbon-nitrogen ratio on Greenville sandy loam soil at different times after various treatments.**

Type of cropping system†	1935			1936			1937			1938			Averages		
	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N
A, Winter green manure	0.302	0.0376	8.0	0.312	0.0447	6.9	0.405	0.0711	5.6	0.302	0.0569	5.3	0.330	0.0526	6.3
B, Winter and summer green manure (largely legumes)	0.460	0.0564	8.1	0.216	0.0666	3.2	0.356	0.0788	4.5	0.465	0.0818	4.9	0.374	0.0709	5.3
C, Summer green manure	0.356	0.0438	8.1	0.272	0.0512	5.3	0.429	0.0599	7.1	0.428	0.0617	5.2	0.371	0.0542	6.8
D, Winter cereal and summer legume	0.412	0.0578	7.1	0.288	0.0697	4.1	0.496	0.0818	6.0	0.429	0.0682	6.2	0.406	0.0694	5.9
E, Winter cereal and summer legume (not fertilized)	0.316	0.0466	6.7	0.277	0.0577	4.8	0.436	0.0726	6.0	0.308	0.0553	5.5	0.334	0.0581	5.7
F, Kudzu permanent cover	0.367	0.0508	7.2	0.311	0.0639	4.8	0.436	0.0694	6.2	0.459	0.0826	5.5	0.393	0.0667	5.9
G, Bermuda grass sod	0.403	0.0515	7.8	0.333	0.0620	5.3	0.503	0.0816	6.1	0.380	0.0746	5.0	0.405	0.0674	6.0
H, Cash crop rotation with summer legumes	0.326	0.0459	7.1	0.260	0.0585	4.4	0.441	0.0706	5.9	0.327	0.0585	5.5	0.339	0.0584	5.8

*The original average organic carbon and total nitrogen of soil samples taken in the fall of 1934 of all the plats were 0.306% carbon and 0.0319% nitrogen, a C/N ratio of 9.6. There were only slight variations in the plats.

†A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.

nitrogen and carbon, this is definitely not in proportion to the amount of green manure added.

The data for the nitrogen and carbon in the Norfolk soil are given in Table 5 and shown graphically in Fig. 2. Both nitrogen and carbon have been increased rather consistently by all the cropping systems, with a tendency for a gradual build up of the nitrogen during the first three years and then a decline for the fourth year. The carbon shows much more variation, but the general trend is for the carbon to accumulate more rapidly than the nitrogen. Thus the carbon-nitrogen ratio has been broadened in most cases. In the average for the period,

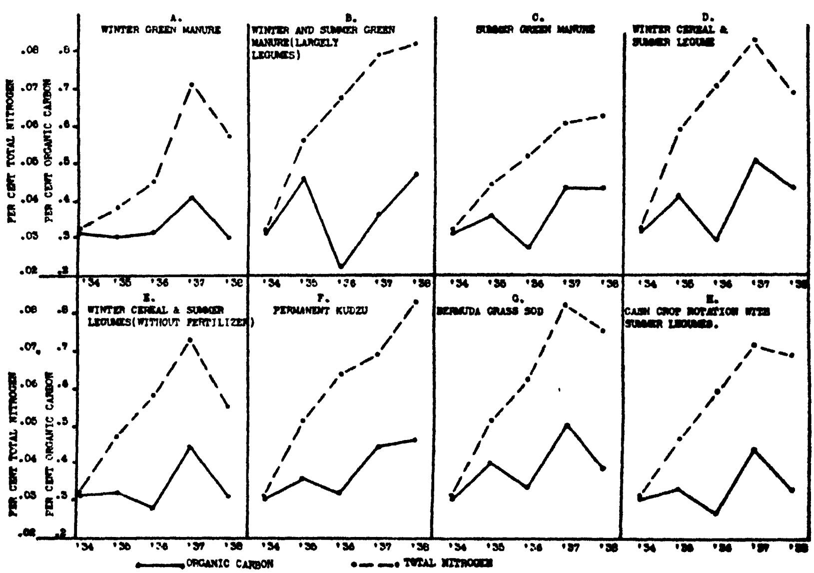

FIG. 1.—Annual change in total nitrogen and organic carbon in Greenville sandy loam soil under different systems of management. All plots except E received 400 pounds annually of 4-8-4 fertilizer.

there are only three systems that have narrowed the carbon-nitrogen ratio below the original. These are the two systems with winter cereal and summer legume (D and E) and the kudzu (F). The greatest conservation of both carbon and nitrogen has been from the bermuda grass sod. System D, which received the greatest amount of green manure during the four years, ranks fifth in average carbon and fourth in average nitrogen. There seems to be no relationship between the amount of green manure added and the nitrogen and carbon accumulated during the period under study.

For the purpose of showing the contrast in the two soils, the relative yields of green material per acre and the average nitrogen and carbon contents of the two soils have been brought together in Fig. 3. First it will be noted that there is a marked similarity between the yields of the crops on the two soils. This is in contrast to the high nitrogen level occurring with all systems on the Greenville soil com-

TABLE 5.—*Content of organic carbon and total nitrogen, also carbon-nitrogen ratio on Norfolk sandy loam soil at different times after various treatments.**

Type of cropping system†	1935			1936			1937			1938			Average		
	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N	C, %	N, %	C/N
A, Winter green manure	0.426	0.0306	13.9	0.386	0.0388	9.9	0.593	0.0584	10.1	0.380	0.0345	11.0	0.446	0.0406	11.0
B, Winter and summer green manure (largely legumes)	0.440	0.0299	14.7	0.442	0.0385	10.9	0.555	0.0613	9.0	0.544	0.0465	11.6	0.495	0.0441	11.2
C, Summer green manure	0.512	0.0441	12.4	0.469	0.0477	9.8	0.543	0.0606	8.9	0.476	0.0473	10.0	0.500	0.0499	10.0
D, Winter cereal and summer legume	0.434	0.0341	12.7	0.451	0.0408	11.0	0.446	0.0683	6.5	0.464	0.0529	8.7	0.449	0.0490	9.2
E, Winter cereal and summer legume (not fertilized)	0.213	0.0355	6.0	0.463	0.0435	10.6	0.595	0.0560	10.6	0.386	0.0369	10.44	0.414	0.0430	9.6
F, Kudzu permanent cover	0.252	0.0383	6.5	0.552	0.0550	10.0	0.597	0.0623	9.5	0.554	0.0569	9.5	0.489	0.0531	9.2
G, Bermuda grass sod	0.568	0.0445	12.7	0.487	0.0547	8.9	0.778	0.0780	9.9	0.531	0.0513	10.3	0.591	0.0571	10.4
H, Cash crop rotation with summer legumes	0.493	0.0327	15.0	0.321	0.0400	8.0	0.485	0.0573	8.4	0.440	0.0441	9.9	0.435	0.0435	10.0

*The original average organic carbon and total nitrogen content of soil samples taken in the early fall of 1934 of all the plats were 0.293% carbon and 0.0299% nitrogen. Carbon-nitrogen ratio of 9.8. There were only slight variations in the plats.

†A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.

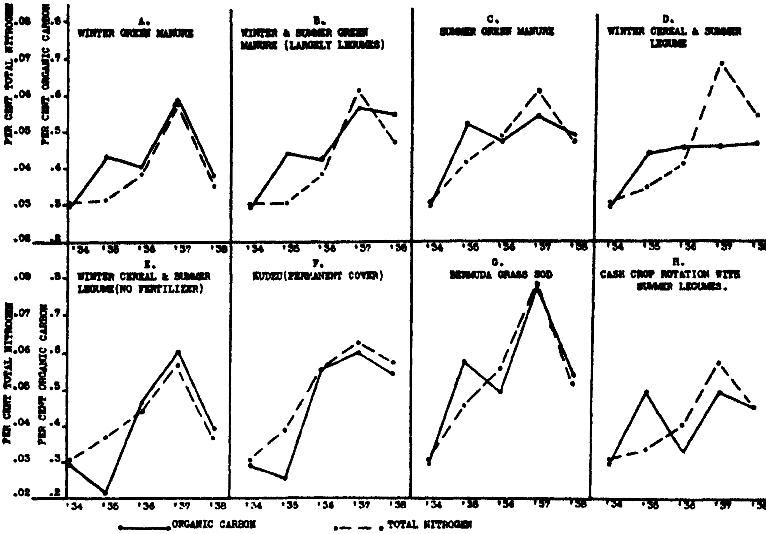

FIG. 2.—Annual change in total nitrogen and organic carbon in Norfolk sandy loam soil under different systems of management. All plots except E received 400 pounds annually of 4–8–4 fertilizer.

pared to the nitrogen level in the Norfolk soil. A further contrast is shown by the higher level of carbon for all the systems on the Norfolk

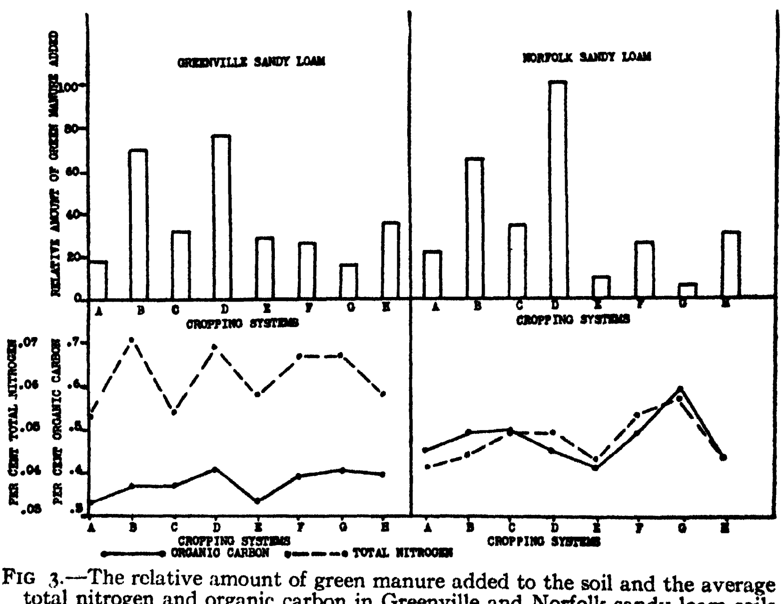

FIG 3.—The relative amount of green manure added to the soil and the average total nitrogen and organic carbon in Greenville and Norfolk sandy loam soils under different systems of management, 1935–38, taking treatment D on Norfolk sandy loam as 100.

compared to the Greenville soil. Thus there is a marked difference in the carbon-nitrogen ratio from the same systems of management on the two soils. There has been a narrowing of the carbon-nitrogen ratio in the Greenville soil largely due to the accumulation of nitrogen, whereas there has been a slight broadening of the carbon-nitrogen ratio in the Norfolk soil due to a greater accumulation of carbon. It is apparent that conditions are more favorable in the Greenville than in the Norfolk soil for the complete destruction of carbonaceous materials. Likewise, there is a greater conservation of nitrogen in the Greenville soil. It is believed that both of these are due to greater leaching of available nitrogen in the Norfolk soil since it has considerably less colloidal material, silt and clay, especially in the B layer. The yield of the crops from system D on the two soils tends to support this view. In this system, the soil is occupied the maximum amount of time during the year, thus leaching should be held to a minimum. The yields of the crops and especially the rye in the winter are greater for the Norfolk than for the Greenville soil. (See Tables 2 and 3.)

The pH data for the soils are given in Table 6. The original pH of all the plats on both soils ranged around 5.8 with only slight variations in plats. It will be noted that the pH has gradually become lower under all systems of management on both soil types with only one exception. This is on the Greenville soil under system F (kudzu) where the pH is about the same after four years of treatment as at the beginning.

EXPERIMENT ON TIFTON SANDY LOAM

PLAN AND PROCEDURE

In 1926, a series of corn and cotton green manure plats were established on Tifton sandy loam soil located at the Georgia Coastal Plain Experiment Station at Tifton, Georgia.[6] These plats have been carried on continuously since that time. Details of the experiment are described elsewhere (6). Two series of plats are planted to the same winter green-manure crops each year, while the summer crops of corn and cotton are rotated. The green-manure crops include Austrian winter peas, monantha vetch, hairy vetch, and Abruzzi rye. For the cotton and corn that follow the green-manure crops, the plats are divided so that one-half of each plat receives nitrogen in the fertilizer and the other half receives none. A 3–9–5 and 0–9–5 fertilizer at the rate of 1,000 pounds per acre are applied to the cotton and a 2–10–4 and 0–10–4 at the rate of 500 pounds per acre are applied to the corn.[7] In presenting the data given here, only the averages for the different green-manure crops with and without nitrogen in the fertilizer are given.

[6]This experiment is cooperative between the Divisions of Soil Fertility Investigations and Forage Crops and Diseases of the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Georgia Coastal Plain Experiment Station. The field phases of the work are under the supervision of J. L. Stephens of the Bureau of Plant Industry at Tifton, Georgia.

[7]The fertilizer constituents are given in the order of ammonia, phosphoric acid, and potash. The 2 and 3% ammonia are equivalent to 1.65 and 2.47% nitrogen, respectively.

TABLE 6.—*The pH values of Greenville and Norfolk sandy loam soils following various cropping systems.*

Type of cropping system*	Greenville sandy loam†					Norfolk sandy loam†				
	1935	1936	1937	1938	Av.	1935	1936	1937	1938	Av.
A, Winter green manure	6.02	5.57	5.64	5.12	5.59	5.72	5.75	5.79	5.20	5.62
B, Winter and summer green manure (largely legumes)	6.03	5.78	5.52	5.10	5.61	5.57	5.48	5.54	5.06	5.41
C, Summer green manure	5.85	5.77	5.45	5.27	5.59	5.65	5.32	5.62	5.15	5.44
D, Winter cereal and summer legume	5.89	5.73	5.63	5.46	5.68	5.66	5.66	5.67	5.37	5.59
E, Winter cereal and summer legume (not fertilized)	6.13	5.78	5.76	5.69	5.84	5.87	5.63	5.76	5.48	5.69
F, Kudzu permanent cover	5.60	5.60	5.50	5.83	5.63	5.64	5.33	5.50	5.25	5.43
G, Bermuda grass sod	5.73	5.70	5.52	5.46	5.60	5.83	5.81	5.55	5.42	5.65
H, Cash crop rotation with summer legumes	5.77	5.55	5.64	5.27	5.56	5.97	5.93	5.55	5.27	5.68

*A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.
†The original pH of Norfolk and Greenville soils at beginning in the fall of 1934 was pH 5.8.

The soil in this experiment is a Tifton sandy loam. It resembles the Norfolk except that the subsoil has a darker yellow color with more fine silt and clay and it contains rounded iron oxide and sand-clay pebbles which make up about 30% of the volume of the A and B horizons. The soil samples were collected to a depth of 8 inches which is the thickness of the A horizon.

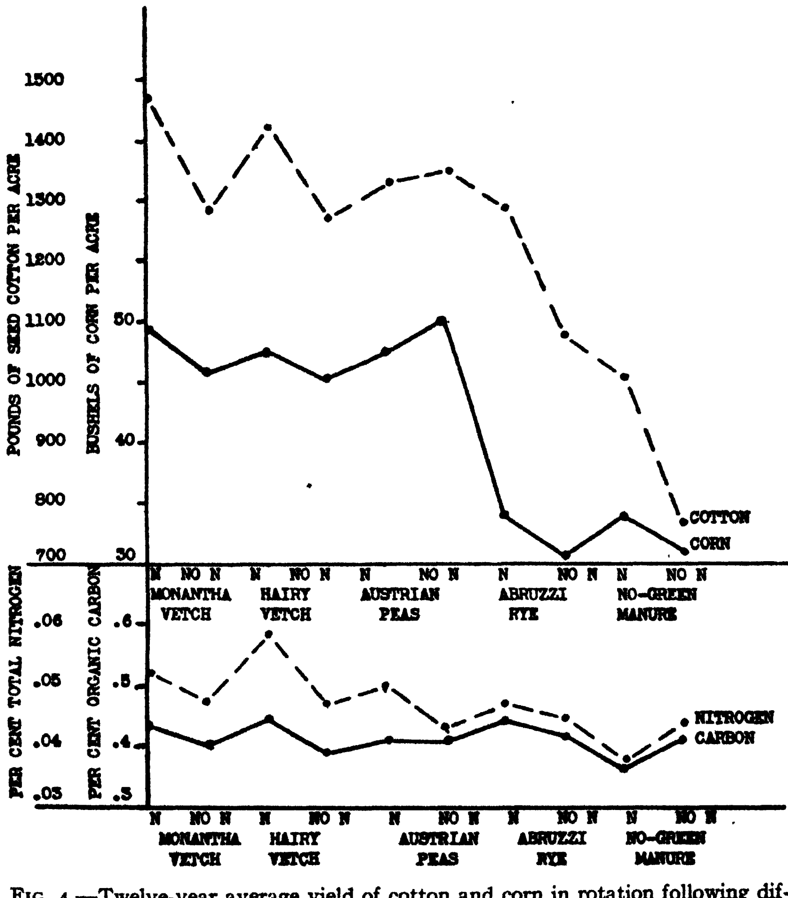

FIG. 4.—Twelve-year average yield of cotton and corn in rotation following different green-manure crops with and without additional nitrogen. The total nitrogen and organic carbon at the end of the period. Tifton sandy loam.

EXPERIMENTAL DATA

The chemical analysis of the soil sampled in 1939 and the average annual crop yields are shown in Table 7 and graphically in Fig. 4. The chemical data represent the status of the total nitrogen, organic carbon, and pH of this soil after 12 years of continuous cropping with the use of the different green-manure crops as compared to no green manuring.

TABLE 7.—*Influence of winter green-manure crops on carbon and nitrogen content of Tifton sandy loam soil and on yield of cotton and corn, experiment started in 1926.*

Green manure crop		pH 1939†	Nitrogen, 1939, %†	Organic carbon, 1939, %†	C/N ratio	Av. yield of green manure in lbs. per acre, 1926–37‡	Av. yield of corn in bu. per acre, 1926–37‡	Av. yield of seed cotton in lbs. per acre, 1926–37‡
Monantha vetch:	A*	5.4	0.052	0.428	8.2	—	48.6	1,474
	B	5.3	0.047	0.401	8.5	19,877	45.8	1,286
Hairy vetch:	A	5.2	0.058	0.444	7.6	—	47.8	1,424
	B	5.3	0.047	0.393	8.4	12,772	45.7	1,266
Austrian peas:	A	5.35	0.050	0.409	8.2	—	47.6	1,333
	B	5.3	0.043	0.406	9.4	12,837	50.3	1,351
Abruzzi rye:	A	5.7	0.047	0.442	9.4	—	34.4	1,290
	B	5.75	0.045	0.421	9.3	6,510	30.6	1,079
No green manure:	A	5.8	0.037	0.364	9.8	—	33.9	1,010
	B	5.5	0.044	0.407	9.2	—	31.2	772

*A, nitrogen in fertilizer; B, no nitrogen in fertilizer.

†The pH of the soil of the various plats at the beginning of the experiment in 1926 ranged very near 6.1, with insignificant variations from plat to plat. The nitrogen of the plats was 0.041% for eight plats, 0.040% for one and 0.042% for one, averaging 0.041%. The carbon content of the two plats averaged 0.43% with variations from 0.39 to 0.44%.

‡The yields of green manure crops, corn, and cotton were taken from the 18th Annual Report of the Georgia Coastal Plain Experiment Station, Bulletin 29, pages 36 and 37 (1937–38).

It will be noted that very good average yields of corn and cotton have been produced where all three of the legume green-manure crops were grown and that the rye has produced yields of cotton that are higher than with no green manure, but not as high as with the legumes. In the case of corn after the rye, the yields are about the same as with no green manure. The maximum yield of cotton was produced following monantha vetch where nitrogen was added in the fertilizer whereas the maximum yield of corn was produced following Austrian peas where no nitrogen was added in the fertilizer. The hairy vetch gave the second highest yield of cotton where nitrogen was added in the fertilizer and the monantha vetch the second highest yield of corn also with nitrogen added in the fertilizer. The Austrian peas without any nitrogen added in the fertilizer gave higher yields of both cotton and corn than did either monantha or hairy vetch under the same condition. In this experiment where no nitrogen was added in the fertilizer, Austrian peas seem to be the most efficient green-manure crop.

The total nitrogen and the organic carbon in the soil appear to be rather closely correlated with the yields of the crops in the case of the data for the monantha and hairy vetch. This correlation is not maintained when the Austrian peas and the rye data are considered. In general, however, the largest crop yields are from the same plats showing the highest nitrogen and carbon. Here again, as with the yields, the Austrian peas without nitrogen added in the fertilizer are an exception. Neither the nitrogen nor the carbon in the soil on this plat are as high as from the rye plats, yet the yields of the crops are considerably above those from the rye plats. Therefore, factors other than the total nitrogen and the organic carbon must have played a part in the yields of the crops produced. While one of the factors involved may be the availability of the nitrogen during the growth of the succeeding crops, the data would indicate that a factor other than nitrogen is involved.

The pH of this soil is lower on all plats than at the beginning of the experiment, being a little more pronounced on the plats receiving leguminous green manure.

DISCUSSION

The data presented tend to lead to the conclusion that it is not of great importance that the nitrogen and carbon be built up to high levels in order to produce good crops on the soils studied. For example, good yields of cotton and corn have been produced on the Tifton soil with an organic carbon content of about 0.4% and a nitrogen content of about 0.050%; on the Norfolk soil with an organic carbon content of 0.44% and a nitrogen content of 0.044%; and on the Greenville soil with an organic carbon content of 0.34% and a nitrogen content of 0.058% (4). Such levels as these were maintained with the use of green-manure crops in rotations with cash crops. Higher levels of these constituents were attained with the use of more intense systems of green manuring, but the higher levels were not in proportion to the much larger amounts of green manure added, thus indicating that heavy losses of these constituents probably occur when an effort is

made to build them up to a very high level. This is doubtless what Pieters and McKee (5) had in mind when they pointed out that the object of green manuring must be to maintain rather than build up organic matter in the soil. The economical system of green manuring would seem to be one in which annual green-manure crops are grown and returned to the soil at such a time as to supply the succeeding crops with the maximum amount of the decomposition products of the green manure.

Albrecht (2), in discussing the maintenance of organic matter, pointed out that the value of organic matter lies in its dynamic nature and that it functions only as it is destroyed. The data secured under systems D and E in this study seem to substantiate this view. In these two systems the same crops (rye in winter and crotalaria in summer) are grown, system D with commercial fertilizer and system E without fertilizer. The producing power of the soils under these two systems has been greatly modified as is shown in Tables 2 and 3. The nitrogen and carbon data under these two systems do not show such marked differences as to explain the difference in the crop growth on these plats. It is true that the carbon and nitrogen are maintained at slightly higher levels under system D with fertilizer, but the relationship of the carbon to the nitrogen is essentially the same for both of the systems; the average carbon-nitrogen ratios for systems D and E are 5.9 and 5.7 for the Greenville and 9.2 and 9.6 for the Norfolk soils, respectively. Therefore, the difference in the carbon and nitrogen relationships for the two systems does not seem adequate to explain the difference in the producing power of the two soils and neither do the slightly higher levels of the two constituents. It should be noted that values for the carbon-nitrogen ratios in each of the soils in these experiments are distinctly lower than values ordinarily found for surface soils of humid regions. Thus it would seem that the influence of the commercial fertilizer on the dynamic nature of the organic matter under these two systems must play an important part in the producing power of these soils. This presents a problem that needs further study.

SUMMARY

The total nitrogen, organic carbon, and pH of Greenville, Norfolk, and Tifton sandy loam soils under various systems of green-manuring are reported. These systems include the growing of summer and winter green-manure crops in different cropping systems and with varying crop management for soil improvement. The soils used in the experiments are typical of the soils of the same types in the southeastern coastal plain.

The total nitrogen is increased and the organic carbon either increased or maintained under all systems in the experiments. In no case were these constituents raised to levels that correspond to the levels reported for fertile soils in latitudes farther north.

In the Greenville soils nitrogen was conserved at the expense of organic carbon with a resulting narrow carbon-nitrogen ratio of about 6.0, under all systems of management. In the Norfolk soil more accumulation of carbon than of nitrogen was obtained under most of the

systems with the result that the carbon-nitrogen ratio was broadened to around 10.0. The Tifton soil is intermediate in this respect showing a carbon-nitrogen ratio of about 8.0.

The *p*H is generally lowered by the use of green manures on all the soils.

Satisfactory yields of cotton and corn were produced with the following approximate levels of organic carbon and total nitrogen where green manures and commercial fertilizer were applied: 0.44% carbon and .044% nitrogen for the Norfolk soil; 0.34% carbon and 0.058% nitrogen for the Greenville soil; and 0.40% carbon and 0.050% nitrogen for the Tifton soil.

More than one green-manure crop in succession results in higher nitrogen and carbon than one crop per year, but the added gain is not sufficient to justify the loss incurred by tying up the land for the time required. The most economical system for using green manure seems to be one in which the most important cash crop follows the green-manure crop.

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MANAGEMENT—A CURE FOR OVERGRAZED RANGE[1]

AVERIL B. NIELSON[2]

EARLY settlers who came to the Pacific Coast bunchgrass regions saw the finest grassland west of the Rocky Mountains. This grass, covering approximately 61,000,000 acres of land in western Montana, southeastern Idaho, eastern Washington, and central Oregon (8),[3] provided forage for immense herds of deer, elk, buffalo, and antelope, and was to become a valuable range for domestic livestock. During the first years of settlement, abundance of forage and a succession of mild winters provided excellent conditions for new ranchers, and it was not deemed necessary to provide hay or other supplemental feed (7).

Prior to 1861, stockmen suffered heavy losses. Indian wars of the late fifties were a contributing factor. Immediately following the Indian wars, when the stock industry was being re-established, the big snow and freeze of 1861–62 is reported to have killed 90% of the domestic stock in the Washington Territory. Undaunted by these reverses, stockmen brought new herds from Oregon, California, and the East, and did a lucrative business until 1880 when another severe winter is said to have taken a toll of 50 per cent of all livestock. This loss, coupled with still another severe winter just 10 years later, broke up most of the large outfits (7).

EARLY METHODS OF MANAGEMENT

Although the available range was being diminished both in area and in quality, the number of cattle and sheep increased, not only in the Northwest but over most of the western range. Supply overstepped demand with the usual result—prices slipped, then dived downward. Choice beef on the Chicago market in 1885 brought $2.50 a hundred weight. Because it was not profitable to ship $2.50 beef, stockmen held their cattle on the range. Herd increases were such that the range could not support these large numbers under continuous use. The era of overuse was in full swing, and from then to the present most of the range has been given no chance to recover from this early "beating" (5).

As the better ranges were broken for cultivation, the poorer areas were more and more heavily used, and it was not long before many of the ranges were seriously injured. As a result, forage production has been reduced by more than 50% and, on many areas, to only a fraction of the virgin forage yield.

PRESENT CONDITION OF RANGE

As a result of lowered vitality of the more desirable forage plant, not only has production been reduced, but the weakened plants

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Received for publication May 4, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 606.

have become unable to produce fertile, vigorous seed. Meanwhile, the plants of low palatability produce abundant viable seed, setting up bold competition to the weakened desirable plants (6).

Observations of grazing during the three years, 1936, 1937, and 1938, on bunchgrass ranges of southeastern Washington show that growth on moderately-used pastures starts 10 days or two weeks earlier than on pastures overgrazed the previous spring (2).

Often insufficient vegetal cover is remaining to prevent accelerated erosion on many heavily-grazed areas, even when the number of plants present is satisfactory as far as density is concerned (3).

It is difficult to appreciate the great change in the condition of range lands in this region during the past 60 years, where excessive use has been the rule. About 19,000,000 acres of this once virgin grassland in eastern Washington and northeastern and northcentral Oregon have been broken and planted to wheat. Of the remaining 42,000,000 acres, 3,000,000 acres are now classed as severely eroded, with the mantle of top soil lots or worn so thin that the desirable forage plants which it once supported no longer thrive. This vast area will probably remain in its cover of the unpalatable grasses and weeds that now occupy these soils.

An additional 7,000,000 acres suffering from serious erosion not only is subjected to the pernicious invasion of the low value plants now permanently established on the severely eroded soils, but has lost so much top soil that it is doubtful whether, even under the best possible management, these grazing areas can be restored to as much as half their original grazing capacity.

The remainder of the grass range, about 32,000,000 acres, displays lesser degrees of erosion and plant depletion. Fortunately, this greater area can be restored to approximately four-fifths of its original grazing capacity by immediate and continuous application of conservation practices (5).

Run-off and erosion studies carried on by the Intermountain Forest and Range Experiment Station show comparisons of soil and water losses on granitic soils from four different types of ranges in southern Idaho (4). Range lands in southeastern Washington and northeastern Oregon that have similar soil and vegetation as those studied in southern Idaho can be expected to yield similar results under the same treatment. The data obtained by the Intermountain Forest and Range Experiment Station in southern Idaho show that on wheatgrass range virtually no run-off or erosion occurred, as compared with an average of 45.4% run-off and 3.69 tons per acre of eroded material on the downy-chess range, the lupine-needlegrass range, and annual-weed range.

The wheatgrass cover was surprisingly effective in retarding run-off and preventing erosion under all conditions, even on 40% slopes, and with high rainfall intensities, under practices that stimulated grazing. Although much less effective than wheatgrass, downy-chess, from which there was an average of 25.5% run-off and 1.05 tons of eroded soil per acre, was about twice as effective for controlling run-off as lupine-needlegrass and annual weed cover types, and from two to seven times more efficient in preventing erosion.

Steepness of slope in these studies was the most important variable influencing run-off and erosion on the three types of range (1).

STUDIES OF CARRYING CAPACITY

The original vegetal condition of the range, as determined from studies of inaccessible areas and old cemeteries, shows a dense cover of thrifty bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), and perennial broad-leaved forbs, including lupine, balsamroot, yarrow, and other perennial species that compose the major portion of the climax cover. This type of vegetation not only provides a good surface cover (up to 34% density), but also fills the topsoil with an excellent network of roots, holding the soil in place, and aiding in the penetration and infiltration of moisture. Such range has been found to carry 96 animal unit months per 100 surface acres (2).

The present condition of vegetation of virtually all this range shows a decrease in plant vigor and forage density resulting from close grazing year after year. Ranges that have been grazed moderately in the past have an average density up to 25% and a carrying capacity of 70 animal unit months per 100 acres. The severely grazed range has a density of only 12% and a carrying capacity of 11 animal unit months per 100 acres (2).

RANGE PLOT STUDIES

Too early and too heavy grazing is generally believed to affect the composition and density of vegetation to a degree depending upon intensity of use, type of vegetation, character of the soils, degree of slope, and climatic conditions. Much has been published to show the stockmen and farmer the evil effects of overuse, but little has been done in southeastern Washington based on permanent study plots to determine the practicability of different methods of management, or what results can be expected from proper range management.

Range plots were set up in 1936 and 1937 in southeastern Washington to study further the effects of overuse of native grass lands and the value of protection in correcting the effects of overuse. These plots were located on south exposures having relatively shallow soil and where the ranges had been severely grazed in the past and, as a result, were in a more depleted condition than on other exposures.

The 20-year average annual precipitation of the area under study was 19.62 inches; for 1936 it was 13.89 inches; for 1937, 16.37 inches. The soils of the area, prairie silt loam, are highly erodible, whether they are overgrazed native grasslands or seeded pasture, and they tend to wash and gully rapidly following depletion of the organic matter. Accelerated erosion of exposed and trampled soil is a serious problem of both range lands and seeded pasture.

Permanent meter-square quadrats were established on representative ranges that were to be managed properly under a deferred and rotation system of grazing. The quadrats were charted during July 1936, and were recharted again in 1938. The average forage density in 1936 was 3.47% basal density. The plant vigor was very low. The

average height of the bluebunch wheatgrass was 6 inches and that of the Idaho fescue 3 inches.

In 1938, the average forage basal density for all species was 5.03%. The bunchgrasses showed definite improvement in plant vigor and basal density. The height of the bluebunch wheatgrass was 25 inches, an increase of 19 inches over 1936. The height of the Idaho fescue was 10 inches, or an increase of 7 inches. The pasture increased 43% in forage density in the two years and approximately 112% in carrying capacity, as compared with the 1936 condition.

Another severely depleted range was selected to carry on a study of the effect of two years' protection of severely overgrazed range. The native bunchgrasses had almost disappeared; only a few small weakened plants remained as evidence of the original vegetative cover. Barbed-wire fences were constructed on quarter-acre areas representative of the surrounding range. Permanent meter-square quadrats were established, and the vegetation was charted within the exclosures and at nearby points outside, to serve later as comparisons in the study of the vegetal recovery of the bunchgrasses.

The basal ground cover and height of the bluebunch wheatgrass on the outside of the enclosures at the time these plots were recharted on May 5, 1938, was about the same as when first charted in 1936. The basal density of the bluebunch wheatgrass on the unprotected plot was 0.57%, the forage height was 7 inches, and the forage yield 10.9 grams per square meter, or 97.15 pounds per acre green weight clipped 1½ inches above the ground level. The basal density on the protected plot was 1.90%, the forage height had increased to 18 inches, and the forage yield was 207.0 grams per square meter, or 1,841.81 pounds per acre green weight, an increase of 19 times in two years.

The range on which a one-year protection plot was established in the spring of 1937 was in better condition than the one on which the two-year study was made. This is shown in the basal densities of the bluebunch wheatgrass. The physiographic, climatic, and soil conditions were much the same as described for the two-year study. Permanent meter-square quadrats were established within and near the enclosures. These quadrats serve as records for later comparisons on the plant recovery.

In 1938, on the grazed area, basal density for the bluebunch wheatgrass was 0.49%, the forage height was 8 inches, and the forage yield was 79.3 grams per square meter, or 704.35 pounds per acre green weight. The basal density of the protected plot was 2.72%, forage height 16 inches, and yield 275.5 grams per square meter, or 2,428.8 pounds per acre green weight, an increase of 3.44 times the forage yield of the grazed range.

DISCUSSION AND SUMMARY

Range studies were made to determine the relative rate of recovery of key species, namely, bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*), under proper management and protection as a basis for recommendations and adjustments in range management plans. Plots were located in pastures which were

owned by local ranchers. Neighboring farmers and stockmen have had an opportunity for regular observation.

The following conclusions were reached as a result of the plot studies:

1. Bluebunch wheatgrass starts growth 10 days to two weeks earlier on pastures moderately used than on those overgrazed the previous spring.
2. Improper management not only reduces the yield of the better forage but also exposes the soil to serious erosion.
3. Studies of the virgin bunchgrass range revealed an estimated carrying capacity per 100 surface acres of 96 animal unit months. Estimated carrying capacity was 70 animal unit months on moderately over-grazed range and only 11 animal unit months per 100 surface acres on severely overgrazed range.
4. Range properly managed under a deferred and rotation system of grazing increased 43% in forage density and 112% in carrying capacity in two years.
5. Bluebunch wheatgrass severely overgrazed previous to protection increased approximately 19 times in forage yield under two years protection from grazing.
6. One-year's protection brought an increase of 3.44 times in forage yield of the bunchgrass the following season.

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SUNFLOWER AS AN INDICATOR PLANT OF BORON DEFICIENCY IN SOILS[1]

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DURING the season of 1935 walnuts containing poorly developed kernels were produced in both irrigated and non-irrigated orchards on certain soil types. Soil moisture determinations made during the growing season in these orchards showed that the moisture was always above the wilting percentage. On the other soil types walnuts containing heavy, well-developed kernels were produced although the soil moisture attained the wilting percentage by harvest. Up to the present, therefore, it has not been possible to relate poor filling entirely to unsuitable moisture conditions.

Soil moisture studies have been made in walnut and filbert orchards of the Willamette Valley since 1930. The wilting coefficients have been determined by the use of plants to extract the moisture in the soils to the wilting point (5).[3] Buckwheat, oats, wheat, coleus, and several types of sunflowers were used in tests to ascertain their suitability as indicator plants in making the wilting point determinations. With the more fertile soils all of the plants made satisfactory growth, but with some of the heavier and poorer soils and especially those taken from the deeper horizons, most plants failed to make satisfactory growth. Of the plants tested, the common sunflower proved the most satisfactory in some cases but not in others. Attempts to grow sunflowers on some soils by planting seed in soil taken from a depth of 4 to 6 feet resulted in complete failure. In the case of soil taken from a depth of 6 feet or more, only the cotyledonary or seed leaves developed and the terminal bud died. The plants grown in the soil taken from a depth of 4 feet made a fair growth for a short time, but later the newer leaves became chlorotic and distorted.

Unsuccessful attempts were made to provide conditions satisfactory for normal growth of the sunflower indicator plants by supplying them with a so-called basal nutrient solution.[4] When such a nutrient solution was used regularly the cotyledons of the sunflower plants growing in soil taken at a depth of 6 feet or deeper sometimes ex-

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[3]Figures in parenthesis refer to "Literature Cited", p. 621.

[4]The "basal nutrient solution" supplied calcium, magnesium, potassium, sulfur, phosphorus, and nitrogen. This type of nutrient mixture was at one time called a complete nutrient before the importance of minor elements was recognized.

panded to several times the normal size and thickness, but the terminal buds would not grow. In soil taken from the fourth foot or nearer the surface of the same profile the plants made a larger growth, developing one or more pairs of true normal leaves. The symptoms of malnutrition of the plants were slower in appearing when watered with a nutrient solution, but they ultimately developed and to the same degree. Furthermore, large sunflower plants with strong root systems when transplanted from flats to the soil cans used for wilting percentage determinations and watered with a basal nutrient solution for 10 days to establish a root system developed the abnormal conditions of the leaves and buds before the tests were completed.

Studies were undertaken in 1936 to determine if some element was deficient in the soils of the walnut orchards which produced poorly filled nuts. In addition to the usual elements contained in a full nutrient solution, zinc, manganese, copper, boron, and others were included singly in the solutions used. The only normal plants grown on the soil taken from the 4 to 6 feet horizons were those that received boron. The abnormalities of the sunflower plants grown on soils without boron were identical to those observed during the wilting point studies. This led to more extensive studies with other soil types to determine the extent of the boron deficiency and its possible relation to the filling of walnut kernels.

METHODS

SOIL TYPES STUDIED

In this study, soils of the following series were used: Sites and Melbourne of sandstone and shale origin; Aiken and Olympic of igneous rock origin; Salkum, Carlton, Amity, and Willamette of the old valley filling; and Newberg of the recent river bottom soils. For the sake of brevity and simplification, only the results obtained with the Aiken, Amity, Melbourne, and an unidentified soil from the Dalles, Oregon, are herein reported. The results obtained with the other soils are similar. Soil samples were taken in the orchards and in the same locations where moisture studies had been maintained for several years. The first foot of soil was divided into two samples, 0–6 and 6–12 inches; the deeper samples were taken at intervals of 1 foot to a depth of 10 feet. These samples were taken to the greenhouse where they were sifted and placed in the cans in which the plants were grown.

TECHNIC

All plants were grown on the various soil samples in No. 1 tall cans of charcoal plate about 3 × 6 inches in size with the inner surface coated with lacquer. The lacquered cans were used to avoid the plate being pitted by the soil solutions. Samples of 400 grams of soil were placed in each can since tests with this small amount of soil quickly showed which elements most limited the growth of plants.

There were four replications in each series. Two of the treatments received no boron and two received boron in addition to whatever other nutrient was used. In preliminary studies, solutions containing boron were made up from borax so that 1, 2½, 25, and 125 parts of boron could be added conveniently to one million parts of soil by weight. When boric acid was used in place of borax the results were similar. The effects of the elements N, P, K, and S were studied singly and in combinations. Then each element in turn was omitted from the "basal nutrient

solution". Nitrogen was supplied as calcium nitrate; phosphorus and potassium as a mixture of KH_2PO_4 and K_2HPO_4 when both potassium and phosphorus were needed. Potassium chloride was used to supply potassium without the phosphorus, and $CaH_4(PO_4)_2$ to supply phosphorus without the potassium. Sulfur was supplied as magnesium sulfate or as calcium sulfate. To determine the effects of these various solutions on plant growth when added to soil samples taken from a complete soil profile required a total of 456 cans.

Seven sunflower seeds were planted in each can and later each culture was thinned to five plants. The plants were started sometimes by watering the soil with distilled water and sometimes by watering with nutrient solutions from the first. All nutrient treatments were applied in the form of dilute solutions of a strength similar to that commonly used in water culture work. Not more than 1,000 cc of culture solution were added to a single can during the period of study. This provided enough of the essential elements N, P, K, and S for at least 15 grams dry weight of growth or more than the maximum growth yet obtained per can. The actual concentrations of solutions used were such as to provide 0.0351 gram K, 0.02 gram N, 0.0217 gram P, 0.0217 gram Ca, and 0.0168 gram Mg in 100 cc of solution. The application in any one day usually did not exceed 50 cc of nutrient solution. Toward the end of the period of study the plants were usually watered with distilled water to avoid overfeeding with nutrients. In the early growth stages, additional water needed for growth other than that supplied by the nutrient solution was provided as distilled water and watering was done once or twice daily as needed. Need for water was determined at first by daily weighing of the cans to determine the loss of moisture. Later, appearance of the soil and past experiences were the guide to watering. The usual procedure was to add nutrient solution on alternate days, keeping a record of the amount added.

Notes were made weekly, as a rule. When the first symptoms of nutritional disturbances appeared, they were recorded and described, and again at the end of the growth period a more detailed record was made to identify and describe the appearance of plants receiving different treatments. Appearance of the foliage and type of growth resulting from the omission of various elements were described when the omissions resulted in striking symptoms. In most cases measurements of the height of the plants were made at weekly or 10-day intervals and each measurement reported is the average of 10 plants. At the end of the experiment the top growth was harvested, dried, and weighed.

RESULTS OF STUDY

BORON DEFICIENCY SYMPTOMS IN THE SUNFLOWER

With extreme boron deficiency, the growth of the sunflower plant was restricted to the cotyledonary or seed leaves. (See Fig. 1.) These sometimes attained an abnormal size of 3 inches in length and several times the usual thickness. The size seemed to be influenced in part by the soil and in part by the nutrient solution added. These abnormally large leaves transpired very little water and tended to remain turgid as the soil dried. Dead spots appeared at the margins of the leaves and gradually increased in size and number. Wilting symptoms as shown by true leaves were sometimes totally lacking in these abnormal seed leaves.

The most common symptoms of boron deficiency were cessation of terminal growth, accompanied with small cupped-under leaves, often

somewhat chlorotic near the terminal. Growth in height was therefore restricted somewhat in proportion to the severity of the boron deficiency. Attention was first directed to the importance of boron as a result of using weak solutions that added about 5 p.p.m. of boron to the soil. This caused new growth from a lateral bud even after growth in height had entirely stopped. The new shoot usually came out at the side of the old stem after the boron was applied to the soil and then the plant would continue to make normal growth.

FIG. 1.—Extreme boron deficiency symptoms on sunflowers. Terminal buds killed. Growth practically restricted to cotyledons. Grown on sandy loam soils from the Dalles, Ore. Soil series unknown.

A mildew appeared on the sunflowers during August and September of both 1936 and 1937. It was noticed first on the seed leaves of the boron-deficient plants. In severe cases, this condition was followed by mildew on the upper leaves of the same plants. The boron-treated plants showed very little, if any, mildew at the same time that boron-deficient plants were white with the fungus.

If the non-treated plants made what appeared to be a normal growth for a time before boron deficiency symptoms appeared, there was a tendency for the stem to split. This symptom, however, was not consistent enough to be used as an indication of boron deficiency.

A shortage of moisture aids in bringing out boron deficiency symptoms. In the greenhouse, repeated partial wilting of the sunflower plants has been used to intensify symptoms. Recovery from partial wilting is complete when the plants are grown on soil to which boron has been added. Boron-deficient plants may or may not recover from similar treatment. Addition of lime to the soil growing the sunflowers also intensifies symptoms of boron deficiency. This has been observed repeatedly though no data in this regard are presented in this paper.

The sunflower shows very clear and definite symptoms of boron deficiencies; and because it can be readily grown under greenhouse conditions with ordinary labor, its use has been adopted as an indicator plant and grown on soils or in nutritive solutions. If it does not show boron deficiency symptoms within a short time, one can be reasonably sure sufficient boron is being supplied for its normal growth. If the sunflower plants show definite boron deficiency symptoms, the response of other plants should be studied since the soil may not supply sufficient boron for their requirements.

BORON DEFICIENCY SYMPTOMS IN OTHER PLANTS

In an effort to determine the reactions of other plants to a possible boron deficiency, a number of plants were grown on a soil which had produced symptoms of boron deficiency in sunflowers. On this soil beans and tomatoes showed extreme symptoms of boron deficiency. The bean leaves became chlorotic, the growth was depressed and little or no blossoming occurred, and there was no set of fruit. The first noticeable effect on the tomato plants was a reddish or bronze color of the small terminal leaves, followed by dying of both terminal leaves and buds. No blossoms were produced and the old leaves became lighter in color where boron was deficient (Fig. 2).

Turnips and radishes were not as sensitive to low levels of boron as sunflowers, beans, and tomatoes. There was a distinct difference in size of top growth in favor of the plants supplied with boron. Near the end of the experiments the turnips and radish plants became

FIG. 2.—Tomatoes. Can No. 145, no boron; Can No. 152, 2½ p.p.m. boron added. Grown on Melbourne clay loam.

heavily infested with aphis and white fly. A selenium spray was used on all the plants with the result that those not treated with boron were killed. Plants treated with boron were seriously burned but rapidly overcame the injury.

Clover, vetch, peas, cabbage, and celery showed little or no response to boron in experiments of 10 weeks duration. Four ornamental greenhouse plants, poinsettia, snapdragon, asparagus fern, and forget-me-nots already rooted when the test started, also showed no response to boron applications on this soil.

Corn, oats, and barley plants showed tip burning on the leaves from an application of 2½ p.p.m. of boron to this soil. These plants seem very sensitive to excess boron. The untreated plants at first were noticeably more vigorous and of better color than the treated plants, but by the end of the experiment no difference could be noted.

Pansies were found to be very sensitive to applications of boron. The plants treated with 2½ p.p.m. of boron barely remained alive while the untreated plants were normal in appearance.

AMOUNT OF BORON USED TO CORRECT BORON DEFICIENCY

The amount of boron that could be added to the soils without causing injury to the plants was very limited and quite variable depending somewhat on the nature of the soils employed.

When 5 p.p.m. of boron were added to certain sandy soils there was some toxicity and addition of more than this amount to heavier soils proved toxic. In some cases on the heavier soils when only 1 p.p.m. was added, the supply of boron became exhausted before the experiment was completed as was indicated by the development of boron-deficiency symptoms in the plants. The application of 2½ p.p.m. of boron to the soil has in nearly all cases proved an adequate treatment and has prevented the occurrence of boron deficiency symptoms even when the plants were grown to maturity.

DISTRIBUTION OF AVAILABLE BORON IN THE SOIL PROFILE

The available boron in the soil profile was studied by using the sunflower as an indicator plant. The results varied with different soil types and somewhat with previous farm practices, particularly that which affected the humus content of the soil. Sunflowers showed boron deficiency symptoms at once when grown on samples taken at a depth of 5 and 6 feet from a Willamette silty clay loam soil located in an old fence row which probably had not been disturbed for over 30 years. No boron deficiency symptoms were visible after 30 days on the plants grown on samples of this soil taken from the upper 3 feet, but at the end of 39 days deficiency symptoms appeared on sunflowers grown on soils from the second and third feet. No abnormality was discernible in plants in the surface foot of soil at the end of the experiment. Only the surface foot of soil failed to show boron deficiency and below this depth the deficiency as indicated by sunflowers was greater with increasing depth.

In the adjoining land fruit trees have been grown with clean cultivation for 25 years preceeded by grain farming for an unknown period of years. Annual winter crops have been regularly grown in the

orchard for 25 years. On the cultivated soil boron deficiency appeared in the plants grown in the fourth, fifth, and sixth foot soon after the seed leaves appeared. The deficiency symptoms were present in the plants grown on soil samples taken from all depths at the end of 30 days. The deficiency symptoms were therefore more marked in sunflowers grown on soil samples of comparable depths from the old cultivated field than from the undisturbed soil.

This behavior was probably related to the amount of organic matter which had been returned or is present in the soil from the cultivated area and the unfarmed fence row where all growth has remained on the soil. Probably no organic materials have ever been removed from the uncultivated soil. Analysis shows 4.96% organic matter for the soil of the fence row and 3.54% for the cultivated plot, respectively, in the upper 6 inches. The average humus content to a depth of 3 feet is more than 60% greater for the fence row soil than for the cultivated soil (Table 1). In the greenhouse 50 grams of well-rotted dried manure added to 400 grams of the old cultivated soil resulted in the growth of normal plants. In all soils studied to date in the greenhouse this amount of organic matter has furnished sufficient boron so that no deficiency symptoms have appeared in sunflowers. The correction of boron deficiency by the use of manure in the field has not been demonstrated. The greater humus content of the upper 3 feet of soil in the fence row may account for less pronounced shortage of available boron.

TABLE 1.—*Humus content of cultivated and uncultivated soil, Willamette silty clay loam.*

Depth, inches	Uncultivated soil, fence row, %	Cultivated soil orchard, %	Difference, %
0– 6	4.96	3.54	1.42
6–12	4.28	2.24	2.04
12–24	3.33	1.84	1.49
24–36	1.29	0.88	0.41
Average	3.465	2.125	1.34

RATE OF GROWTH IN RELATION TO AVAILABLE BORON

The comparative availability of boron in different soil horizons can be judged in part by the rate of growth of the plants. Rate of growth was recorded by height measurements of sunflowers in the various soils with and without boron. As soon as the cotyledons were unfolded and the terminal growth with true leaves began, height measurements were made on all the plants in the different groups and repeated at approximately weekly intervals. The comparative rate of growth of plants in Aiken clay loam samples from the horizons 6 to 12 inches, the fifth, and ninth foot, all treated with complete nutrient, is given in Fig. 3.

The graph shows the different variations in boron deficiency as indicated by the rate of growth of plants in soil samples taken from these different depths. There was a very slight response to boron in

the growth of the plants where boron was added to the samples of soil taken down to and including the fifth foot. Below the fifth foot the response increased to a maximum in the ninth foot. Only three levels, the surface 6 inches, the fifth, and the ninth foot depths are shown in the graphs to simplify the diagram. The tendency was for plants in the upper horizons of Aiken clay loam soil without boron to outgrow those treated with boron during the earlier stages of growth. Later those receiving boron made the most growth. However, the difference in rate of growth between plants grown in the upper level of soil to which boron had been added and those in soil without additional boron was very small. Below the fifth foot the response to

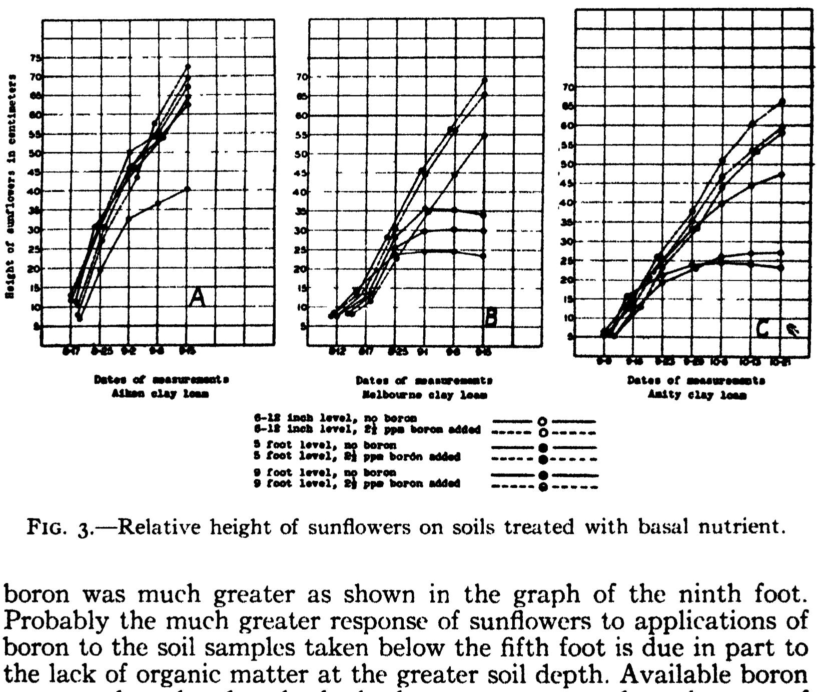

FIG. 3.—Relative height of sunflowers on soils treated with basal nutrient.

boron was much greater as shown in the graph of the ninth foot. Probably the much greater response of sunflowers to applications of boron to the soil samples taken below the fifth foot is due in part to the lack of organic matter at the greater soil depth. Available boron seems to be related to both the humus content and to the rate of humus renewals in soils. This indicates that fresh organic matter may serve as a source of boron.

With sunflowers grown in Aiken clay loam where no boron was added, mild boron deficiency symptoms were visible soon after the development of the cotyledon leaves. These became very noticeable in the levels below the fifth foot as shown in the data from the ninth foot. Above the fifth foot of soil boron deficiency was not serious until near the end of the experiment.

Basaltic soils, of which the Aiken clay loam is a representative, as a rule produce less marked symptoms of boron deficiency with the sunflower than any other soils tested from the Willamette valley of Oregon. Basaltic soils vary in the response to additions of boron

according to the type and past cultural treatments but characteristically show little response except in the lower depths.

The comparative rate of growth of sunflowers on Melbourne clay loam soil samples from different depths is shown by the graphs in Fig. 3. The plants on soils from all depths treated with basal nutrient with and without additional boron made a comparable growth only for the first 5 days. During the next 8 days plants receiving no boron and grown on soil samples taken at depths from the fifth to the tenth foot slowed down in growth. Those plants in soil from the 6 to 12 inch horizon continued their growth for another week. By that time all plants with basal nutrient but without boron had made their maximum growth while those receiving boron continued with no apparent diminution in growth rate for two more weeks or until the end of the experiment at which time many plants were beginning to bud. The difference in vigor of plants grown on soil samples from the surface 6 inches and from a depth of 10 feet in the same Melbourne clay loam soil and supplied with basal nutrient solution with and without boron is illustrated in Fig. 4. In the upper 6-inch sample without boron the plants had grown considerably taller than plants grown in the sample from the tenth foot. When, finally, the available boron was exhausted, growth ceased. The plants grown in the sample from the tenth foot ceased growth some time before. Where boron was added to comparable samples, the plants continued to grow although those in the surface sample grew more rapidly and became taller.

In Fig. 3 is also shown the height of sunflowers grown on samples of Amity silt loam receiving basal nutrient solutions with and without boron. The data of Fig. 3 indicate that the Amity silt loam is comparatively low in available boron, though not quite as low as the Melbourne clay loam. It is interesting that when boron is supplied with the basal nutrient, growth in soil from the fifth foot depth is somewhat better than growth in the surface soil under similar conditions. Even the tenth foot depth of soil when supplied with basal nutrient and boron supports nearly as good growth as the surface soils. These trials have been repeated several times with similar results.

DRY WEIGHT OF PLANTS IN RELATION TO AVAILABLE BORON

In addition to measuring the height of the plants grown in the various soil samples with and without boron and basal nutrient solution, at the end of each experiment the dry weight of the plants was determined. These data, given in Table 2, show the response of sunflower plants to boron when grown on soil samples taken from different levels. The Aiken soil shows least response in sunflower growth when treated with boron. There is practically no response in the 6 to 12 inch level or in the fifth foot. Both the Amity and Melbourne soils show marked response to boron treatments as indicated by sunflower growth. There is a response on soil samples from all depths, but a greater response on soil samples from the fifth and tenth foot levels than from the 6 to 12 inch depth. Thus, dry weight determinations fully verify the height measurements, indicating plant responses to boron.

The data of Tables 3, 4, and 5, giving dry weights of sunflowers grown on soil samples from each horizon of a 9- or 10-foot profile,

FIG. 4.—Sunflower plants on Melbourne clay loam treated with basal nutrients and boron. Cans Nos. 13, no boron added; Nos. 15, 2½ p.p.m. boron added.

indicate that the crop-producing power of the Melbourne, Aiken, and Amity soils, without nutrient or boron treatment, was about equal.

TABLE 2.—*Average dry weight in grams of single sunflower plants grown on samples of soil taken at different depths from three representative soils, all plants being supplied with a basal nutrient solution.*

Soil	Average dry weight of single plants in grams		
	Without boron	With boron	Difference due to boron
Aiken clay loam:			
6–12 inches	0.990	0.988	+0.002
5 feet	0.976	1.028	+0.052
9 feet	0.405	0.930	+0.525
Amity silt loam:			
6–12 inches	0.467	0.855	+0.388
5 feet	0.266	0.930	+0.664
10 feet	0.242	0.882	+0.640
Melbourne clay loam:			
6–12 inches	0.575	0.987	+0.412
5 feet	0.270	1.324	+1.054
10 feet	0.338	1.161	+0.823

Growth of sunflowers was also about equally good in the soil from the 0 to 6 inch and the 6 to 12 inch levels. Soil taken at any depth below 2 or 3 feet produced about equally satisfactory growth, but not as good growth as the soil from the top foot or two.

Response of sunflowers to basal nutrient was dependent upon the capacity of the soil from the different levels to supply boron. With the little growth made on untreated soils, little boron was required.

TABLE 3.—*Dry weight in grams of 10 sunflower plants (two replications of five plants each) grown on samples of Melbourne clay loam taken at different depths to which were added distilled water or basal nutrient solution with or without 2½ p.p.m. of boron.*

Depth at which soil samples were taken	Average dry weight in grams of 10 sunflower plants			
	Distilled water		Basal nutrient solution	
	No boron	2½ p.p.m. boron added	No boron	2½ p.p.m. boron added
0– 6 inches	3.460	3.265	10.295	12.230
6–12 inches	3.235	2.990	5.755	9.870
2 feet	2.695	2.540	5.625	13.340
3 feet	1.525	1.890	5.205	13.340
4 feet	1.360	1.495	2.740	13.275
5 feet	1.370	1.520	2.706	13.245
6 feet	1.295	1.775	3.193	12.795
7 feet	1.220	1.490	2.810	11.353
8 feet	1.565	1.650	2.565	13.285
9 feet	1.535	1.785	3.896	12.934
10 feet	1.450	1.450	3.385	11.610
Average weight for 10 plants	1.834	1.986	4.38	12.479

TABLE 4.—*Dry weights in grams of 10 sunflower plants (two replications of five plants each) grown in samples of Aiken clay loam taken at different depths to which were added distilled water or basal nutrient solution with or without 2½ p.p.m. boron added to the soil.*

Depth at which soil samples were taken	Average dry weight in grams of 10 sunflower plants			
	Distilled water		Basal nutrient solution	
	No boron	2½ p.p.m. boron added	No boron	2½ p.p.m. boron added
0– 6 inches	2.790	2.960	9.493	9.291
6–12 inches	2.749	3.213	9.900	9.880
2 feet	2.419	3.100	9.280	10.215
3 feet	2.073	2.360	8.110	9.855
4 feet	1.995	2.150	6.320	10.930
5 feet	2.245	2.255	9.769	10.289
6 feet	1.605	1.925	6.390	10.455
7 feet	1.405	1.760	5.535	10.400
8 feet	1.290	1.540	5.540	10.435
9 feet	1.270	1.460	4.500	9.301
Average weight for 10 plants	1.984	2.272	7.483	10.105

TABLE 5.—*Dry weight in grams of 10 sunflower plants (two replications of five plants each) grown on samples of Amity silt loam taken at different depths to which were added distilled water or basal nutrient with or without 2½ p.p.m. boron added to the soil.*

Depth at which soil samples were taken	Average dry weight in grams of 10 sunflower plants			
	Distilled water		Basal nutrient solution	
	No boron	2½ p.p.m. boron added	No boron	2½ p.p.m. boron added
0– 6 inches	2.520	2.240	5.710	9.140
6–12 inches	2.445	2.130	4.670	8.550
2 feet	1.870	1.810	3.390	9.290
3 feet	1.740	1.600	1.900	9.565
4 feet	1.550	1.720	2.320	9.355
5 feet	1.570	1.880	2.660	9.300
6 feet	1.875	2.160	2.525	10.075
7 feet	1.605	2.240	2.470	9.420
8 feet	1.720	2.170	3.155	9.515
9 feet	1.850	2.590	2.440	8.430
10 feet	1.595	2.290	2.420	8.820
Average weight of 10 plants	1.849	2.075	3.060	9.223

When nutrient was supplied, the rapid growth soon exhausted the supply of available boron in the more deficient soils or soil horizons. Only the surface 6 inches of the Melbourne soil furnished nearly an adequate amount of boron. The 6 to 12 inch and the second and third

foot depths furnished about half as much available boron as the 0 to 6 inch depth. From the fourth foot down the available boron was much lower. The Amity soil supplied half as much available boron in the 0 to 6 inch level as the Melbourne soils as indicated by plant growth. The 6 to 12 inch level was about equally as good as the 0 to 6 inch level for supplying available boron in both soils. The second and third foot levels of the Amity soil were poorer in available boron than similar depths in the Melbourne. Below the third foot the two soils were nearly equally poor in their capacity to supply available boron. The Aiken soil showed comparatively little boron deficiency even when basal nutrient was used down to the sixth foot depth. Below that depth boron deficiency was marked

With both boron and basal nutrient supplied, all depths and all three soils produced plants relatively uniform in size. Based upon the data of Tables 3, 4, and 5, and considering the whole soil profile, the Amity soil was most deficient in available boron and the Aiken soil least deficient. The growth increases for basal nutrient without boron on the entire profile were approximately 65, 139, and 277% for the Amity, Melbourne, and Aiken soils, respectively With boron in addition to basal nutrient, the increases over basal nutrient without boron were approximately 201, 185, and 35% for the Amity, Melbourne, and Aiken, respectively. Considering only the top 3 feet where feeding roots probably obtain most of their nutrient, the increases from basal nutrient without boron were 82, 146, and 267%, and for basal nutrient and boron over basal nutrient alone 133, 81, and 7% for the Amity, Melbourne, and Aiken soils, respectively. These data bring out the relative importance of boron in addition to basal nutrient in the three soils. Boron was nearly as important as other nutrients in Amity and Melbourne but much less important in the Aiken soil.

DISCUSSION

These studies indicate that sunflowers can be successfully used as an indicator of the level of available boron in soils. Since the sunflower is undoubtedly a heavy user of boron, the deficiency as indicated by this plant can not be taken as proof of a deficiency for all plants. But if the sunflower plants when grown on a certain soil and watered with a basal nutrient solution do not show any boron deficiency symptoms, this soil probably has plenty of available boron for most plants. The methods used in this work permit a test to be completed in 8 to 10 weeks or less and can be used to establish or eliminate boron as a probable limiting factor in plant nutrition in a given soil. By taking soil samples from definite horizons the distribution of available boron in the soil profile can be established.

Whether these data can be fully applied to field conditions, remains to be determined. Tests under greenhouse conditions with small amounts of soil may give altogether different results from those obtained in the field with large quantities of soil. This procedure has been successfully used at the suggestion of one of the authors for detecting boron deficient soils in Idaho (2). Field tests are now under way but it will require several years to investigate fully the need of

boron for nut and fruit crops. Since this work was completed, Bouquet and Powers (1, 3) have reported correction of celery crack and beet canker from the use of boron in field treatments.

Withholding water caused boron deficiency symptoms to develop more severely on the plants grown under greenhouse conditions. Under field conditions, dry seasons may make the need of boron seem more pronounced, while seasons of well-distributed, abundant rainfall will minimize the deficiency. Thus, certain seasonal conditions have a great effect on the appearance of the plants and the apparent boron deficiency.

When large amounts of fertilizers are added to field or orchard crops, the limited supply of available boron may be used up and boron deficiency symptoms will appear where they would not have been evident without the application of the fertilizers. Since the symptoms may develop at any stage of growth, crops harvested before full maturity might be less affected than those where full maturity takes place. In sunflowers, normal growth may continue until the plant is ready to bloom. A deficiency of boron at this stage of growth inhibits flower development while plants with the requisite amount of boron develop normal flowers and seed.

Boron deficiency can be expected to be more pronounced on soils that are eroded, such as the Melbourne series derived from sandstone. Erosion removes the top soil and boron deficiency is usually greater in the deep soil than in the surface horizons. Since humus and available boron seem to be associated in this study, the available boron is probably relatively limited in eroded soils in part because of diminished humus supply.

Boron deficiency as a cause of poor nutrition of apples (4) has been well established in many parts of the world, but boron deficiency as a cause of poor filling of walnut kernels has not been proved as yet. While analysis of walnut leaves from trees grown on the boron-deficient soils shows a relatively low boron content, no definite proof has yet been found that boron deficiency is concerned with poorly filled walnut kernels, possibly due to the short period for which trials have been conducted.

SUMMARY

Definite boron deficiency symptoms developed in sunflowers grown in the greenhouse on various soil types. Other plants varied widely in the development of these symptoms and in their reaction to boron applications on the same soils.

Boron deficiency can be corrected by adding 1 to 2½ p.p.m. of boron to the soil when small samples are used for growing plants in the greenhouse.

Soils long clean cultivated and low in organic matter contain less available boron than uncultivated soils of the same type. Humus depletion seems to aggravate boron deficiency and the addition of an adequate amount of compost to the soil corrects the deficiency.

Boron deficiency is shown in sunflowers by a cessation of growth of the terminal bud, reduced dry weight, and abnormal leaf characteristics.

Available boron is usually greatest in the upper 3 feet of soil. In the depths below 3 feet the shortage is often extreme.

Unless plants are supplied with available nutrients sufficient to produce good growth, boron deficiency may be over-shadowed by other deficiencies.

Adequate amounts of available basal nutrients make possible sufficient plant growth so that boron deficiencies quickly become evident.

Soils vary widely in the amount and distribution of available boron. This may be due to the origin of the soil, weathering, cultivating practices, erosions, humus supply, and other factors.

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THE BORON CONTENT OF SOME IMPORTANT FORAGE CROPS, VEGETABLES, FRUITS, AND NUTS[1]

J. S. McHargue, W. S. Hodgkiss, and E. B. Offutt[2]

The Department of Chemistry of the Kentucky Agricultural Experiment Station has been investigating for some time the necessity of some of the so-called minor elements in the economy of plants and animals. Boron is one of the minor elements which has received attention in our laboratory to ascertain its importance as a nutrient for the growth of plants. The results obtained (1, 2)[3] showed that boron was an essential element for the growth of plants used in the experiments.

Since that time we have been interested in methods for the determination of boron contained in plant and animal tissues. Because of the rather widespread boron deficiencies reported by other investigators in certain forage crops, vegetables, fruits, and nuts, we undertook an investigation to ascertain the boron content of some of the principal forage crops, fruits, vegetables, and nuts consumed in foods in our locality. It will be observed from the tables that some of the samples were grown in rather widely separated parts of the country. The methods used are described in a previous paper by Hodgkiss (3). Most of these data were obtained by Dr. Hodgkiss using the colorimetric quinalizarin procedure.

EXPERIMENTAL DATA

The samples analyzed in the present study are arranged in natural groups in Table 1 and the boron content reported in parts per million of the moisture-free material.

A comparison of some of the results obtained by the colorimetric and spectrographic procedures are reported in Table 2.

In some of the samples there is very close agreement between the two methods of analysis, but in others the agreement is not so good. This is possibly due to several causes, one of which is the lack of a suitable salt base to which boron standards and samples can be added in order that the effect of extraneous elements in the samples will be minimized. This matter is still being investigated.

DISCUSSION OF THE RESULTS

From the foregoing results it is to be observed that there are some rather wide variations in the boron content of the different groups of plant materials analyzed.

Cereals, potatoes, and hays, in the order named, contained the smallest amounts of boron. On the other hand, with the exception of

[1]Contribution from the Department of Chemistry of the Kentucky Agricultural Experiment Station, Lexington, Ky. The investigation reported here is in connection with a project of the Kentucky Agricultural Experiment Station and is published by the permission of the Director. Also read before the Division of Agricultural and Food Chemistry of the American Chemical Society at the Cincinnati meeting in April, 1940. Received for publication June 11, 1940.

[2]Head of Department and Assistant Chemists, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 626.

TABLE 1.—*Boron content of various plant and animal materials.*

Material	Boron, p.p.m.
Cereals:	
Corn, white, Ky.	1.17 (2)*
Corn, yellow, Ky.	2.30 (3)
Wheat, Ky.	0.59 (3)
Oats, ?	1.02
Barley, Ky.	0.64
Rye, Ky.	1.50
Average	1.19
Pasture and hay crops:	
Bluegrass, Ky.	11.80
Bluegrass, Ky.	6.00
Orchard grass, Ky.	5.20
Timothy and clover mixed, Ky	3.30
Average	6.57
Leguminous hays:	
Red clover, Ky.	31.30
Alfalfa, normal, Ky.	33.30
Alfalfa, abnormal, Ky.	47.00
Lespedeza, Ky.	18.10
Lespedeza, Ky.	20.30
Average	30.00
Vegetables:	
Potatoes, Irish, Ky.	4.43 (3)
Potatoes, sweet, tubers+boron, Ky.	4.10
Potatoes, sweet, leaves+boron, Ky.	105.00
Potatoes, sweet, leaves−boron, Ky.	4.40
Potatoes, sweet, leaves normal, Ky.	79.50
Average of tubers	4.31
Average of leaves	92.25
Turnips, Ky.	30.60
Tomatoes, red, Ky.	12.60
Tomatoes, yellow, Ky.	14.70
Carrots, roots, ?	41.00
Carrots, tops, ?	45.00
Cabbage, Florida	11.50
Celery, Florida	22.50
Lettuce, California	16.80
Spinach, Texas	31.50
Kale, Virginia	13.30

*Average of number of samples indicated.

TABLE 1.—*Continued.*

Material	Boron, p.p.m.
Vegetables:	
Beans, pinto, ?	17.10
Beans, soy, Ky.	41.00
Peas, garden, ?	8.40
Average	24.45
Fruits:	
Apricots, dried, Calif.	38.20
Dates, dried, Egypt	8.20
Figs, dried, Egypt	13.70
Orange, pulp and juice, Calif.	11.00
Orange, peel, Calif.	10.00
Orange, pulp and juice, Florida	10.40
Orange, seeds, Florida	17.70
Peaches, dried, Calif.	38.20
Prunes, dried, Calif.	25.10
Raisins, dried, Calif.	21.40
Average	19.39
Nuts:	
Hickory nut, kernels, Ky.	9.60
Hickory nut, shells, Ky.	5.60
Pecan, kernels, Ga.	2.60
Pecan, shells, Ga.	8.20
Hazelnut, kernels, Ky.	24.40
Hazelnut, shells, Ky.	48.00
Walnut, kernels, Ky.	15.40
Peanut, kernels, ?	17.70
Average of kernels	13.94
Average of shells	20.60
Milk:	
Cow's, Holstein, Ky.	0.93
Cow's, Jersey, Ky.	0.93
Mare's, Ky.	1.80
Average	1.22
Egg yolk, Ky.	0.60

TABLE 1.—*Concluded.*

Material	Boron, p.p.m.
Leaves of trees:	
Dogwood, Bell Co., Ky., sandy loam soil	22.5
Hickory, Laurel Co., Ky., sandy loam soil	59.0
Hickory, Bell Co., Ky., sandy loam soil	160.0
Sourwood, Laurel Co., Ky., sandy loam soil	68.0
Sourwood, Bell Co., Ky., sandy loam soil	66.0
Sweet gum, Laurel Co., Ky., sandy loam soil	19.2
Sweet gum, Fayette Co., Ky., sandy clay loam soil	29.4
Average	60.78
Miscellaneous samples:	
Acorns, pin oak, Ky.	10.6
Tobacco, burley, Ky.	67.0
Tobacco, dark, Ky.	28.9
Tobacco, stalks, Ky.	11.4
Tobacco, seed, Ky.	6.1
Kelp, Pacific Coast, Calif.	270.0
Average (kelp omitted)	24.8

TABLE 2.—*Boron content of various material as determined by different methods.*

Material	Boron in p.p.m.	
	Colorimetric method	Spectrographic method
Acorns (pin oak)	10.6	6.3
Alfalfa	33.5	33.0
Beans, soy	41.0	30.0
Beans, pinto	17.1	14.0
Bluegrass	11.8	8.1
Leaves, sweet gum	19.2	23.0
Leaves, hickory	160.0	155.0
Lespedeza	18.0	15.0
Orange pulp	15.0	10.4
Tobacco stalks	11.0	10.2

the sample of kelp, the leaves of the forest trees contained the largest amount of boron. Leguminous hays, tobacco, fruits, and leafy vegetables contained an intermediate amount of boron.

In the case of the leaves from forest trees there is some indication of selective absorption of larger amounts of boron by the hickory leaves than by the sourwood and dogwood leaves. All of the leaves were collected at the same time from trees that grew in the same type of sandy loam soil on Pine Mountain near Cumberland Gap in Bell County, Kentucky, and within a distance of approximately 50 feet of one another. The leaves were collected after the end of the growing season on October 13, 1939. The foliage of each tree had attained its

maximum characteristic autumnal coloration, yellow and tan in the case of the hickory, dull red for the dogwood, and brilliant red in the leaves of the sourwood. However, the sample of hickory leaves which was collected in Laurel County, Kentucky, on June 10, 1939, grew in a similar type of sandy loam soil as those in Bell County, but they contained less than one half as much boron as the latter.

Scribner (4) reports finding by spectrographic examination a number of rare elements in hickory leaves from a tree that grew on a pegmatite vein near Amelia, Virginia. These findings indicate that the mineral content of hickory leaves may vary considerably with the soil on which the trees grow.

From the results obtained for the boron content of the various materials reported in this paper it would appear that a boron deficiency is not likely to occur in animals receiving an adequate supply of any of the edible materials as food.

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CROP SEQUENCE STUDIES IN NORTHWESTERN OHIO[1]

R. M. SALTER AND J. G. LILL[2]

CROP rotation, in which cultivated crops, small grains, soybeans, and sod crops are grown in definite order, is accepted practice on farms in northwestern Ohio and considerable information has been accumulated regarding the soil-depleting or soil-conserving effects of the individual crops commonly included. It is also possible to evaluate fairly well the effects of the rotation as a whole upon soil productivity. On the other hand, there exists little published information regarding the order in which the cultivated crops and grain crops should occur in the rotation for most profitable returns. For several years, the Ohio Agricultural Experiment Station and the Division of Sugar Plant Investigations of the U. S. Dept. of Agriculture have cooperated in the experiment on the Northwestern Experiment Farm at Holgate, Ohio, designed to determine the effects of certain crops upon the crops following.

The soil in the area where this project is located is a Brookston clay, a heavy, dark-colored soil derived from calcareous glacial drift, of level topography, and considered well adapted to sugar beets, alfalfa, and corn when well tiled. The experimental area is only fairly well drained, the spacing of approximately 4 rods between lines of tile being somewhat wider than is optimum for this land. Other experiments on this farm point to poor physical condition as the chief limiting factor to high crop yields on this soil, fertilizers and even manure being relatively ineffective compared to such practices as the plowing down of deep-rooted legumes as alfalfa and sweet clover.

The number of crops that could be included in this crop sequence experiment was limited because the plan of the experiment and the plot arrangement used made it necessary that the soil preparation of all plots be done at the same time and in the same manner for the various crops. The crops used were sugar beets, corn, oats, soybeans for hay, and soybeans for seed. These crops were planted, cared for, and harvested according to ordinary farm methods. In the disposition of the crop residues, the sugar beet tops, corn stover, and soybean haulm were left on the land producing the crop while the oat straw and soybean hay were removed.

All of the crops were grown under each crop sequence condition each year in order to avoid the possibility of seasonal variations masking the effects that the individual crops might have upon the yields of the crops following. This was accomplished by growing the various crops in narrow, randomized strips in replicated blocks. The strips extended in one direction one season and were at right angles in the next season. Thus, after the first season, each crop followed it-

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[2]Associate Director and Chief, Division of Agronomy, Ohio Agricultural Experiment Station, and Associate Agronomist, Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

self and also followed each of the other crops. Since the experiment was confined to the same area each year, the experimental crop the second season became the preparatory crop for the third season, and so on. The experiment covered the period 1935 to 1939, inclusive, giving four years' harvests for interpretation.

The annual mean yields for the individual crops, presented in Table 1, show wide variations associated with seasonal conditions and a fair level of production for all crops except sugar beets. Variability of response among the different crops to seasonal influences is shown by the fact that neither all the high yields nor all the low yields were obtained during the same season; also by the variation among crops in the relative yield fluctuations during the four year period, shown in Table 2.

TABLE 1.—*Average yield of each crop for each of the four seasons.*

Crop	1936	1937	1938	1939	Average
Sugar beets, tons	8.26	3.02	4.91	2.79	4.74
Corn, shelled, bu.	30.5	15.6	44.6	38.1	32.2
Oats, bu.	59.7	23.5	47 4	33.9	41.1
Soybean hay, tons.	1.36	2.44	2.13	3 02	2.24
Soybean seed, bu.	18.9	26.1	28.1	31.2	26.1

TABLE 2.—*Variation in yield caused by seasonal factors.*

Crop	Acre-yield, 4-year average	Difference between extreme high and low yields	Difference as percentage of the mean yield
Sugar beets, tons	4.74	5.47	115.4
Corn, shelled, bu.	32.2	29.0	90.1
Oats, bu.	41.1	36.2	88.1
Soybean hay, tons	2.24	1.66	74.1
Soybean seed, bu.	26.1	12.3	47.1

In Table 3 are shown the 4-year average yields of each crop for each of the five crop sequences involved, also yield differences required for specific odds for significance. Since the soil was prepared at the same time and in the same manner for all crops, since no fertilizer was applied throughout the experiment, and since it may be assumed that the seasonal influences are largely eliminated by averaging the 4 years' results, it is believed that significant variations in the yield of individual crops represent primarily differential effects of the preceding crops.

It is evident that the preceding crop had considerable effect upon the yields of the crops other than soybean hay and soybean seed. Corn yields appeared to be most influenced by the nature of the preceding crop, oats and sugar beets showed a lesser but still marked influence, whereas soybeans, either for hay or seed, were affected little, if at all. It is also interesting to note that the soybeans showed the least fluctuation in yield associated with seasonal variations. These differences among the various crops are somewhat more evident if the variations in yield of the individual crops associated with

TABLE 3.—*The 4-year average yield of each crop for the various crop sequences.*

Crop grown	Crop grown during the previous season				
	Sugar beets	Corn	Oats	Soybean hay	Soybean seed
Sugar beets, tons	4.17	4.31	4.65	5.41	5.18
Corn, shelled, bu.	34.2	21.6	30.1	40.3	34.8
Oats, bu.	42.8	34.7	35.4	46.9	45.8
Soybean hay, tons	2.23	2.29	2.29	2.21	2.17
Soybean seed, bu.	26.0	26.5	25.7	26.0	26.2

Significance* determined for	Odds of	When difference is at least
Sugar beet yields	99 to 1	0.51 ton
Corn yields	99 to 1	2.8 bu.
Oat yields	99 to 1	3.2 bu.
Soybean hay yields	1 to 1	No significant difference
Soybean seed yields	1 to 1	No significant difference

*From statistical evaluation of individual crop summaries.

different crop sequences are stated as percentages of the respective mean yields, as is done in Table 4.

TABLE 4.—*Extreme variations in the yield of the various crops caused by the influence of the previous crop compared to the mean yields.*

Crop	Acre-yield, 4-year average	Difference between extreme high and low yields caused by crop sequence	Difference expressed as percentage of the mean yield
Sugar beets, tons	4.74	1.24	26.2
Corn, shelled, bu.	32.2	18.7	58.1
Oats, bu.	41.1	12.2	29.7
Soybean hay, tons	2.24	0.12	5.4
Soybean seed, bu.	26.1	0.8	3.1

It is of interest to note that, except for the soybean hay and soybean seed crops, the yield obtained when a particular crop followed itself were the poorest or close to the poorest obtained among the different crop sequences. This fact is emphasized by the data in Table 5

TABLE 5.—*Average yearly advantage indicated for the various crop sequences over the results obtained in continuous cropping.*

Crop	Crop grown in previous season				
	Sugar beets	Corn	Oats	Soybean hay	Soybean seed
Sugar beets, tons	0.0	0.14	0.48	1.24	1.01
Corn, shelled, bu.	12.6	0.0	8.5	18.7	13.2
Oats, bu.	7.4	−0.7	0.0	11.5	10.4
Soybean hay, tons	0.02	0.08	0.08	0.0	−0.04
Soybean seed, bu.	−0.2	0.3	−0.5	−0.2	0.0

showing the average yearly advantage for the various crop sequences over the results obtained in "continuous cropping".

It is obvious that if one were to attempt to set up a hypothetical 5-year rotation including each crop grown in this experiment, it would be impossible to include only the most advantageous sequences, since the results indicate the greatest possible advantage when corn, oats, and sugar beets each follow the soybean hay crop. It is possible, however, to choose an arrangement of crops which will give the greatest total advantage for the rotation as a whole. The following represents this most advantageous arrangement of the five crops and indicates the total 5-year advantage for the sequences employed compared to continuous cropping in each instance:

Order	Crop	5-year advantage (average annual advantage × 5)
1	Soybean hay	0.4 tons
2	Corn	93.5 bu.
3	Soybean seed	1.5 bu.
4	Sugar beets	5.0 tons
5	Oats	37.0 bu.

It should not be inferred from the foregoing that the rotation proposed might be a practical rotation for this region. In fact, such a rotation would probably result in the soil being depleted at a fairly rapid rate since it includes none of the more efficient soil-building sod legumes. It is intended merely to illustrate the usefulness of crop sequence data in planning an efficient crop rotation.

The favorable effect of soybeans upon succeeding crops in this experiment deserves mention since the results are at variance with much other data obtained elsewhere in Ohio. Although definite proof is lacking, it seems probable that the favorable effects of soybeans on this heavy clay soil, relatively well supplied with nutrients but having poor physical properties, may result from the well-known granulating effect of soybeans, whereas, on soils of lighter texture, less well supplied with nutrients, adverse effects may result from a temporary exhaustion of fertility by the soybean crop.

VARIATIONS IN THE DORMANCY OF SEEDS OF THE WILD OAT, *AVENA FATUA*[1]

E. H. TOOLE AND F. A. COFFMAN[2]

IT HAS long been recognized that seeds of the common wild oat (*Avena fatua*) are characterized by dormancy, which may persist for an extended period following maturity. Zade (12)[3] and Atwood (2) have mentioned the very low germination of seed of *A. fatua* when freshly harvested and state that germinability gradually increases after the seed has been in storage for several months. Garber and Quisenberry (7) and Johnson (8) have mentioned the variability in germination of the seed from different plants. Lute (11) called attention to the regional variation in germination of seed of *A. fatua* and suggested that the generally accepted belief that wild oats may be distinguished by their dormancy at harvest is not well founded because of the almost complete lack of dormancy of some lots. Deming and Robertson (6), Larson, Harvey, and Larson (10), and Coffman and Stanton (3) conducted tests which showed that considerable dormancy is found in some varieties of the cultivated oats when freshly harvested. The latter (4) found also that the germinability of fatuoids, or the false wild oat forms occurring in cultivated varieties, appeared to be similar for that character to the varieties in which each was found

Several workers (2, 7, 8, 11) have shown that germination of *Avena fatua* is increased by breaking the seed coat. Atwood (2) and Johnson (8) demonstrated the beneficial effect of increased oxygen concentration during germination, and Johnson (8) obtained a distinctly beneficial effect from soaking the seeds in 1 to 2% of KNO_3 for 24 hours, and some benefit from freezing the seed. However, none of these treatments has resulted in the complete or prompt germination of freshly harvested seed of *A. fatua*.

Unpublished results obtained from the study of *Avena fatua* plants in the greenhouse indicate that a marked variation existed in the promptness of germination of seed collected in different sections of the

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[1]Cooperative investigations of the former Division of Seed Investigations and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication June 24, 1940.

[2]Physiologist, Division of Fruit and Vegetable Crops and Diseases, and Agronomist, Division of Cereal Crops and Diseases, respectively. Acknowledgment is due the following for supplying wild oat (*Avena fatua*) plants for use in these experiments: Ralph W. Smith, Dickinson Substation, Dickinson, N. Dak.; W. B. Nelson and A. M. Schlehuber, Agricultural Experiment Station, Bozeman, Mont.; Glen Hartman, Agricultural Experiment Station, Laramie, Wyo.; D. W. Robertson and J. J. Curtis, Agricultural Experiment Station, Fort Collins, Colo.; Wayne M. Bever, Agricultural Experiment Station, Moscow, Idaho; Harland Stevens, Aberdeen Substation, Aberdeen, Idaho; Rollo W. Woodward, Agricultural Experiment Station, Logan, Utah; A. T. Bartel, Agricultural Experiment Station, Tucson, Ariz.; C. S. Holton, Agricultural Experiment Station, Pullman, Wash.; J. Foster Martin, Pendleton Branch Experiment Station, Pendleton, Ore.; D. D. Hill, Agricultural Experiment Station, Corvallis, Ore.; and Coit A. Suneson, University Farm, Davis, Calif.

[3]Reference by number is to "Literature Cited", p. 638.

United States. This observation prompted the securing of additional information on the comparative germination of seed from different *A. fatua* plants and from different sections. In addition to germination, some data were obtained on the morphologic characters of *A. fatua* from different areas as a further check of their variable nature.

MATERIAL AND METHODS

Through the collaboration of members of the field staff of the Division of Cereal Crops and Diseases of the Bureau of Plant Industry, and of agronomists of several state agricultural experiment stations, plants of *Avena fatua* were received in 1937 from stations in various western states. The seed was threshed by hand preparatory to testing. An attempt was made to use only plump "seed", i.e., containing well-developed caryopses, but no attempt was made to distinguish between primary and secondary kernels of the spikelet. Considerable variation existed in the maturity of the different collections, as well as in the number of seeds per plant available for testing. Some plants had failed to mature and, because of shattering, no seed was obtained from others.

Germination tests of different lots usually were begun the tenth day following collection, although there were a few exceptions owing to delay in the mails.

So far as available, 50 seeds from each collection were included in each test. The seeds were placed between several folds of moist paper toweling and kept in a thermostatically-controlled germinator for 14 days at which time the percentage germinating was recorded. After 14 days at 20° C, the seed remaining ungerminated was transferred to a refrigerator and kept at a temperature of from 3° to 5°C. The seed was protected to prevent drying out. After 2 to 4 weeks the samples were again returned to the germinator at 20° C. This treatment was not effective in breaking dormancy except with a few samples; therefore, the seeds still remaining were dried at room temperature, again moistened, and returned to 20° C. Germination tests were made at this temperature of all samples of which seed remained the following May (1938), or after 9 to 11 months' storage in the laboratory.

As the marked variability in the color of the kernels of *Avena fatua* is widely recognized and as observations indicated that considerable variability also existed in the germinability of seed from different *A. fatua* plants, a request was made for additional material, and numerous individual plant specimens grown in 1939 were received from several points in the western United States. These were examined individually and observations were recorded of the morphologic characters of the kernels. The characters studied in addition to germination were kernel size, lemma color, awn type, size and shape of the basal cavity, and the number and length of pubescence on the back of the lemma and base of the kernel.

EXPERIMENTAL RESULTS

GERMINATION TESTS

The comparative results of the germination tests for 217 individual plants made soon after collection and again after 9 to 11 months had elapsed are summarized in Table 1. When tested at 20° C, approximately 10 days after collection, the average germination of 9,064 seeds at the end of 14 days was 13.8%. Only sufficient seed remained of 115 samples for a second test. In this test, conducted 9 to 11 months

after storage of the seed in the laboratory at room temperature, the average germination was 64.5% of a total of 4,373 seeds.

The germination of the freshly collected seed varied greatly, both for the individual plants from a given locality and for groups of plants from different localities. The 89 collections from the four localities of Moscow, Idaho, Pullman, Wash., and Pendleton and Corvallis, Ore., were characterized by high dormancy. In each group of collections, the percentage of samples with no germination was high and the average germination was low. No freshly harvested sample from these four localities germinated more than 12%. The collections from Logan, Utah, in general, showed a similar high dormancy, although 3 of the 26 samples germinated 46, 70, and 72%, respectively. Among the 82 collections from the four localities, Fort Collins, Colo., Davis, Calif., Dickinson, N. Dak., and Aberdeen, Idaho, a high proportion of the samples germinated more than 50%, and a comparatively high average germination was obtained. In the group of 20 samples from Laramie, Wyo., comparatively few had a very low germination, but only one sample germinated more than 50%.

KERNEL CHARACTERS

The range in kernel characters of the plants obtained from six localities in 1939 is shown in Table 2. The number of plants from Pullman, Wash., and Tucson, Ariz., was small but previous records of more extensive investigations indicate that most of the kernel types present at Pullman are included in this list.

The data indicate a wide variability in the morphologic characters of the *Avena fatua* plants at all points. The variation was wider at some points than at others. Wide variation in size of kernel occurred at all points. All specimens from Dickinson, N. Dak., had black or brown kernels (lemmas), while those from Pendleton, Ore., were all gray. Variations from black to gray were observed among plants obtained from Bozeman, Mont., Pullman, Wash., Fort Collins, Colo., and Tucson, Ariz., and in addition a few yellow specimens were obtained from Pullman. Yellow specimens also have been collected at Fort Collins in other studies.

All florets in all samples bore twisted-geniculate awns regardless of the locality from which the plants came.

Some variation was observed in the size, shape, and prominence of the cavity or scar at the base of the lemma resulting from abscission. Plants in which the cavity was less prominent than usual were found frequently in collections from Fort Collins, Colo., and Pullman, Wash. Except for lemma color, the most widely variable character observed was pubescence on the lemma. Much variability was observed in pubescence on both the back and the base of the lemma. Less pubescence was observed on the back of lemmas from plants grown at Pendleton, Ore., than elsewhere, but wide variation in number and length of hairs on the lemmas was observed among specimens from all other points.

As to basal pubescence, wide variation occurred among plants from all points except Fort Collins, Colo., where the lemmas examined

TABLE 1.—*Germination of seed of wild oats from individual plants collected in 10 localities.*

Locality	Date collected	Total No. of seeds tested	Germination, %: In 14 days at 20° C, Average	Germination, %: In 14 days at 20° C, Range	Germination, %: Additional after 9 to 11 months varied treatments	No of samples tested	Number of samples germinating grouped according to percentage germination in 14 days at 20° C: 0%	1–10%	11–50%	51–75%	76–100%	Retests in May, 1938: No. of samples tested	Retests: Total No. of seeds tested	Retests: Germination in 14 days at 20° C, %, Average	Retests: Germination in 14 days at 20° C, %, Range
Moscow, Idaho	June 16, 1937	1,103	0.5	0–2	0.1	24	19	5	0	0	0	13	325	13.2	0–50
Pullman, Wash.	July 30 to Aug. 6, 1937	700	0.6	0–2	6.4	14	10	4	0	0	0	13	555	64.3	18–95
Pendleton, Ore.	July 29, 1937	1,250	1.5	0–12	10.1	25	18	6	1	0	0	23	1,044	68.2	12–96
Corvallis, Ore.	July 18 and 28, 1937	1,233	2.0	0–12	18.0	26	16	8	2	0	0	19	825	56.8	12–100
Logan, Utah	July 1–24, 1937	1,282	8.4	0–72	2.4	26	18	3	3	2	0	18	425	62.6	0–100
Laramie, Wyo.	Aug. 12 and 23, 1937	636	13.1	0–54	0	20	1	6	12	1	0	2	25	92.0	87–100
Fort Collins, Colo.	July 26–27, 1937	544	44.5	0–88	2.0	14	3	2	2	5	2	9	450	95.3	64–100
Davis, Calif.	June 14–15, 1937	1,136	27.3	0–94	50.1	25	9	4	4	3	5	15	685	71.5	24–100
Dickinson, N. Dak.	Aug. 2, 1937	468	37.6	0–100*	1.3	21	2	1	10	3	5	1	9	100	—
Aberdeen, Idaho	Aug. 16, 1937	712	38.8	0–100	0.7	22	3	4	8	4	3	2	30	80.0	73–87
Totals or averages		9,064	13.8	—	—	217	99	43	42	18	15	115	4,373	64.5	—

*Two records of 100% germination are based on 2 and 8 seeds per sample.

TABLE 2.—*Variability in kernel characters of samples of Avena fatua collected in six localities in 1939.*

Locality	No. of sample plants	Lemma or kernel				Pubescence		Type of germination
		Size	Color	Awn type	Prominence of scar	Back	Base	
Dickinson, N. Dak.	9	Small to large	Black to brown	Twisted	High	Sparse to abundant	Abundant; very short to very long	Rather prompt; rather high.
Pullman, Wash.	5	Small to large	Reddish brown, gray to yellow	Twisted	High to very high	Sparse and long to abundant and very long	Abundant; very short to abundant; very long	Dormant.
Tucson, Ariz.	5	Small to intermediate	Black to gray	Twisted	High to very high	Absent to very abundant; very long	Abundant; medium long to very long	*
Fort Collins, Colo.	13	Small to large	Black to gray	Twisted	Medium to very high	Absent to sparse; very long	Very few to abundant; very short	Rather prompt; rather high.
Pendleton, Ore.	10	Medium to large	Gray	Twisted	Medium to very high	Absent	Abundant; very long to medium; very short	Dormant.
Bozeman, Mont.	15	Small to large	Black to dark gray	Twisted	Medium to very high	Sparse and long to abundant and long	Intermediate to abundant; very short	*

*Not tested.

bore short hairs only. The different plants varied greatly as to number of hairs, however.

In general, wide variability in the morphologic characters of the *Avena fatua* plants was observed among the specimens from all localities; but no correlation seems evident between dormancy and any of the plant characters studied.

DISCUSSION

Notes on the habitat of individual plants were furnished by the collectors, but no association was evident between dormancy and locality, habitat, or general growing conditions. Dormancy was high in samples grown on dry land in eastern Oregon and Washington as well as on irrigated land in Utah and under humid conditions in western Oregon, but was less pronounced in samples from Fort Collins, Colo. (irrigated), Dickinson, N. Dak. (dry land), and Davis, Calif. (semiarid).

Lute (11) has suggested that immature seeds of wild oats are more dormant and slower to after-ripen than mature seeds. Considerable difference in maturity was evident in the material used in this study, and these differences of maturity may have had some effect on the results. For example, 280 seeds collected at Laramie on August 12 germinated 5.4%, whereas 356 seeds collected in the same locality 11 days later germinated 19.1%. Collections at Corvallis were made on two dates 10 days apart and the collections at Pullman 2 to 3 weeks later than at Moscow, only a few miles distant, yet no plant from any of these collections had germinated more than 12% after being in the germinator for 14 days. It would thus appear that maturity was not an important factor in the variability of dormancy reported herein.

When the remnant seed of the samples was tested after 9 to 11 months in storage there was a marked increase in the average germination of the samples from each locality, but even after this long period a marked difference in the behavior of individual samples still was evident. From each locality some samples gave nearly complete germination, whereas others changed very little from the original tests. In general, seed from localities with high dormancy in the first test showed the lowest average germinations in later tests. Samples from Moscow gave a strikingly lower average germinations in tests following storage than did collections from Pullman, only a few miles distant. The Moscow collections were made at an earlier date and presumably were less mature than those from Pullman. It is possible that differences of maturity of seed influenced rate of after-ripening, although it had not led to a difference in germination in the original test.

No tests were made of the effect of pre-chilling freshly harvested seed before it had been put in the germinator at 20° C. After 14 days in the germinator, all samples were protected from drying and stored in a refrigerator at from 3° to 5° C for from 2 to 4 weeks. Following this they were returned to the germinator. Johnson (8) has shown that a secondary dormancy is developed in wild oats by holding the seed moist under conditions unfavorable for germination. However,

considerable additional germination occurred in many of the above-mentioned samples from Davis, Calif., and in a few of those from Corvallis, Ore. None of the samples from other points responded appreciably to this chilling.

All of the samples in these tests were dried and wetted again one or more times during the course of the experiments, yet only a few of the samples from Pendleton, Ore., and two from Pullman, Wash., gave appreciable additional germination following this procedure.

The variability in the morphologic characters of *Avena fatua* is, of course, generally recognized, although probably few fully realize its extent. The reason for this variability is unknown, but from observation by Coffman and Wiebe (5) and by Aamodt, Johnson, and Manson (1) reason exists for believing natural crossing between different *A. fatua* plants may be responsible in part. It seems most probable that *A. fatua* as found in any given locality consists of numerous strains some of which are likely to be segregating hybrids. Segregation could occur both in morphologic and physiologic characters.

The frequency of natural crossing in *Avena fatua* is not known, hence the proportion of segregating lines can not be estimated.

Johnson (9), from a study of delayed germination of *Avena fatua* $\times$*A. sativa*, observed that germinability is dominant over dormancy, consequently the non-dormant segregates in a hybrid population being first to germinate after maturity probably would be killed by any cultural operation or climatic factor unfavorable to the plants. Under such conditions the percentage of dormant individuals might gradually be increased in any given population.

Lute (11) showed that different collections of wild oats may differ in dormancy even after having been grown and harvested under uniform conditions.

It would seem possible that high dormancy in *Avena fatua* at Moscow, Idaho, Pullman, Wash., and Pendleton and Corvallis, Ore., might be related in some way to moisture or cultural conditions favorable to germination of the more promptly germinating strains. Those which germinate promptly are destroyed by winter weather or by cultural practices and a predominance of the more dormant types has resulted. At Corvallis, however, the winters are comparatively mild and killing would be expected only in occasional years. Conversely, dry weather prevailing in late summer and early autumn at Fort Collins, Colo., Dickinson, N. Dak., and Aberdeen, Idaho, may result in a deficiency of soil moisture and little or no germination of any form until spring. Consequently, a lower percentage of dormant types is found. At Davis, Calif., a special condition exists; fall moisture is ample there but the winters are so mild that little winter-killing results and all types would be expected to survive about equally well.

SUMMARY AND CONCLUSIONS

Individual plant samples of wild oats (*Avena fatua*) were collected in 10 localities in the western half of the United States and were tested for germination immediately and again 9 to 11 months later.

A marked difference was found in the proportion of dormant seeds of wild oats from different localities, and a wide variation in dormancy occurred among plants from any given locality.

Plants from six localities, examined for morphologic characters, were found to be more variable in some localities than in others.

There was no indication of association between dormancy and morphologic characters

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BOOK REVIEW

GARDENING WITHOUT SOIL

By A. H. Phillips, New York: Chemical Publishing Co., Inc. 137 pages, illus. 1940. $2.

THIS little book is a brief and inexpensive collation of present information on soilless culture of plants. It is presented as a practical guide to this new subject and does it well. A brief introduction discusses the general field, and is followed by a chapter describing how plants grow. The remainder of the book is divided into discussion of water culture, of culture in mineral aggregates, of nutrient solutions, of soilless culture in practice, and of soilless culture on the farm.

In the appendix are an article by Mullard and Stoughton on "Preliminary Trials in Growing Horticultural Crops in Nutrient Solutions", a brief bibliography, and a list of soilless-culture equipment and sources of supply. (H.B.T.)

AGRONOMIC AFFAIRS

THIRTY-THIRD ANNUAL MEETING OF THE SOCIETY

THE thirty-third Annual Meeting of the American Society of Agronomy will be held in the Drake Hotel, Chicago, Ill., December 4, 5, and 6. The general program of the Society will be held on Thursday morning, December 5, when Dr. E. J. Kraus will speak on "Possible Use of Growth Substances in Agricultural Practice" and Dr. R. M. Salter on "Integrating Soils and Crops Research".

A statement regarding the program for the Crops Section appeared in the June number of the Journal. A recent communication from Dr. S. C. Salmon, Chairman of the Section, urges that all who contemplate appearing on the program submit titles and length of papers at an early date. He states also that the program committee would like to feature one or more sessions devoted to short papers of not more than 10 to 15 minutes, reporting on results of current research. It is not expected that such papers will present material conclusions, but rather that they will serve to stimulate interest and be informative with respect to new lines of research under way or new approaches to old problems. Communications regarding the Crops Section program should be addressed to Doctor Salmon, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

Accommodations may be had at the Drake Hotel for $3 for single rooms and $5 for double rooms. Reservations should be made directly with the hotel.

PROGRAM OF THE SOIL SCIENCE SOCIETY

THE Annual Meeting of the Soil Science Society to be held at the Drake Hotel in Chicago December 4, 5, and 6 will consist of 13 Sectional sessions, one general session, and one dinner meeting. The program for the general session will consist of four papers representing different Sections of the Society. The main speaker at the annual banquet will be Dr. E. C. Auchter, Chief of the Bureau of Plant Industry, U. S. Dept. of Agriculture.

The outline of the Sectional meetings follows:

Section I. Soil Physics.—Chairman, J. F. Lutz, North Carolina State College, Raleigh, N. C.
- Session A. Joint Program with Section IV.
  - Symposium: Interrelationship of the physical properties of soils and plant growth.
- Session B. Miscellaneous Papers.
- Session C. Joint Program with Section II.
  - Symposium: Clay minerals and base exchange.

Section II. Soil Chemistry.—Chairman, M. S. Anderson, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.
- Session A. Miscellaneous Papers:
- Session B. Joint Program with Section IV and Crops Section.
  - Symposium: Interrelation between plant composition, soil type, and fertilization.

Session C. Joint Program with Section I.
(See Session C, Section I).

Section III.—Chairman, A. W. Hoffer, New York State Agricultural Experiment Station, Geneva, N. Y.
Sessions A and B. Miscellaneous Papers.

Section IV.—Chairman, W. H. Metzger, Kansas State College, Manhattan, Kan.
Session A. Joint Program with Section I.
(See Session A, Section I).
Session B. Miscellaneous Papers.
Session C. Joint Program with Section II and Crops Section.
(See Session B, Section II).

Section V.—Chairman, T. M. Bushnell, Purdue University, Lafayette, Ind.
Sessions A and B. Miscellaneous Papers.

Forest Soils Subsection.—Chairman, Herbert A. Lunt, Connecticut Agricultural Experiment Station, New Haven, Conn.
General papers and round table discussion.

Section VI.—Chairman, H. E. Middleton, Soil Conservation Service, U. S. Dept. of Agriculture, Washington, D. C.
Sessions A and B. Miscellaneous Papers.

The chairmen of the various Sections wish to extend their call for papers and to point out that the title of papers to be submitted for the various Sectional programs should be in their hands by September 1. The final date for the submission of abstracts of the papers is September 15. Attention is called to the detailed information on program regulations, governing papers presented before the Society, which appears on page 360 of the 1938 PROCEEDINGS.

REGIONAL GRASSLAND CONFERENCES

AT LEAST four regional technical grassland conferences have been or will be held in the United States this summer, all of which have been sponsored by the Pasture Committee of the American Society of Agronomy and in some instances have been held jointly with sectional summer meetings of the Society.

Conferences already held include the Regional Grassland Conference and Meeting of the Northeastern Section of the Society, Pennsylvania State College, State College, Pa., July 10 to 12; the Western Grassland Conference, Salt Lake City, Utah, July 15 to 17; and the Regional Grassland Conference for the Southeastern Section, Coastal Plain Experiment Station, Tifton, Ga., July 23 to 26. The fourth conference that has come to our notice is to be held at Ames, Iowa, September 11, in connection with the meeting of the Corn Belt Section of the Society at Iowa State College, September 9 to 10.

The programs follow much the same general trend, covering, first, an historical perspective; second, the economic and social impacts; and third, the research and educational needs for the development or

achievement of a grassland agriculture. In each case an effort has been made to acquaint the agricultural leaders of the region with the objectives, procedures, progress, research and educational needs, etc., of the conferences

PROFESSOR C. B. WILLIAMS RETIRES

PROFESSOR C. B. Williams was retired from active administrative duties as head of the Department of Agronomy of the North Carolina State College on July 1. He will continue as a member of the staff, devoting his time to writing and other things.

Professor Williams has been associated with State College since it was established in 1889, graduating with the highest honors in the first class. Since then he has held a number of important positions as follows: 1893-1896 and 1897-1906, assistant chemist of the North Carolina Experiment Station; 1906–24, Head of the Department of Agronomy of the North Carolina Agricultural Experiment Station; 1926-40, Head of the Department of Agronomy, North Carolina State College; 1907–12, Director, North Carolina Experiment Station; 1913-40, Vice-Director, North Carolina Experiment Station; 1917–24, Dean of Agriculture, North Carolina State College; 1920, Chairman, Tobacco Research Committee; 1915, in charge of State Soil Survey.

In announcing Professor Williams' retirement, Dean Schaub, said in part, ". . . . I would like to state that Professor Williams has given long and invaluable service to the agriculture of North Carolina. I am sure, that we all regret that time finally brings us all to retirement age, but we are delighted that Professor Williams is still interested, vigorous, and undoubtedly has many more years of service for the state".

BORON AS A PLANT NUTRIENT

SUPPLEMENT II of a bibliography of literature on boron as a plant nutrient published and reviewed from January through December 1939, with a subject and author index, has been issued by the American Potash Institute of Washington, D. C.

The material, in mimeographed form, is arranged first by crops sub-divided by states. A second section is then divided into separate headings under boron with each sub-divided by states. The same abbreviations and system of numbering the references used in previous bibliographies from the same source have been followed.

NEWS ITEMS

DOCTOR WENDELL BARTHOLDI has been appointed to the position of assistant agronomist at the Rhode Island Agricultural Experiment Station left vacant by the death of Professor Crandall. He will have charge of the work in vegetable research at the station. Dr. Bartholdi received his B.S. degree from the University of Minnesota in 1934, the M.S. from Ohio State University in 1936, and the Ph.D. degree from the University of Minnesota in June 1940. The vegetable research program at Rhode Island consists largely of nutrition studies

with market garden crops. Dr. Bartholdi assumed his new duties on July 1.

DOCTOR L. A. WOLFANGER, Associate Professor of Soil Geography and Land Use, Soils Section, Michigan State College, has been granted leave of absence to teach a special course for the summer in soil geography at Columbia University.

A NATIONAL conference on land classification will be held at the University of Missouri, Columbia, Mo., October 10 to 12, 1940. Attention will be given to theories of land classification, soil factors in land classification, land classification for different purposes, and technics and practices in land classification. This meeting may be of interest to soil scientists, geographers, economists, foresters, geologists, grazing specialists, and others concerned with the larger aspects of land use.

THE AMERICAN POTASH INSTITUTE, Inc , Washington, D. C., has announced the appointment of Errett Deck as its Northwest Representative. In this capacity, Mr Deck will supervise the Institute's agricultural educational program in the states of Washington, Oregon, and Idaho, with headquarters at Puyallup, Wash He replaces Clay A. Whybark who resigned to take a position as agronomist with Hunt Bros. Canning Company.

E. L. PINNELL, recent graduate of the University of Missouri, has been appointed part-time research assistant in corn breeding at the University of Minnesota.

HERBERT CRAMER has been appointed full-time research assistant at the University of Minnesota to work on corn and grasses.

WM. J. WHITE, in charge of the Dominion Forage Crops Laboratory at Saskatoon, Saskatchewan, Canada, is spending the summer at the University of Minnesota, completing his graduate work on the Ph.D. degree.

N. E. JODON, Crowley, La., Rice Experiment Station, is doing graduate work at the University of Minnesota for the summer.

IN JUNE the following men received their Ph.D. degrees in Agronomy and Plant Genetics at the University of Minnesota: W. H. Leonard, Colorado State College; H. Y. Chen, Nanking, China; J. O. Culbertson, Sugar Plants, U. S. Dept. of Agriculture; Charles A. Rowles, University of Saskatchewan; and H. K. Schultz and Miss Marion Hilpert, University of Minnesota.

ACCORDING to an announcement by the U. S. Dept. of Agriculture, Dr. Oswald Schreiner will act as advisor to the Chief of the Bureau of Plant Industry on soil problems connected with the work of the Bureau.

MARTIN NELSON, Head of the Department of Agronomy at the University of Arkansas College of Agriculture since 1908, retired effective June 30. Mr. Nelson was formerly the Dean of the College of Agriculture and since 1920 served the College as Vice-Dean. As

Professor Emeritus, Mr. Nelson's work will consist primarily of writing in the field of agronomy.

R. P. Bartholomew, formerly Associate Professor of Agronomy at the University of Arkansas, is now Head of the Department of Agronomy succeeding Martin Nelson, retired.

C. K. McClelland, formerly Assistant Professor of Agronomy, University of Arkansas, was made Associate Professor of Agronomy effective July 1.

Dr. Paul C. Mangelsdorf, Vice-Director of the Texas Agricultural Experiment Station, has been appointed Professor of Botany at Harvard University and Assistant Director of the Botanical Museum.

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EFFECT OF THE METHOD OF COMBINING TWO EARLY AND TWO LATE INBRED LINES OF CORN UPON THE YIELD AND VARIABILITY OF THE RESULTING DOUBLE CROSSES[1]

ROBERT C. ECKHARDT AND A. A. BRYAN[2]

EXPERIENCE with maize has amply demonstrated the value of certain crosses between early- and late-maturing strains for growing in the short-season areas to which the early strains are adapted. Earliness tends to be dominant in such crosses, and in some combinations where the differences in the seasonal requirements of the strains are not too large it has been possible to obtain in the hybrid particularly all of the earliness of the early parent together with much of the increased plant size and vigor of the late parent. This situation has been amply demonstrated in the past with open-pollinated varieties. It has been found to be equally true of hybrids involving inbred lines and is responsible for the present production and utilization of many commercial double crosses of this kind in some of the corn-growing areas with a relatively short growing season.

In the commercial production of such double-crossed hybrid seed corn a single cross of the two early lines may be crossed with a single cross of the two late lines, (E×E)×(L×L),[3] or two single crosses, each involving an early and a late line, may be crossed, (E×L)×(E×L). The first procedure necessitates planting the two single crosses on different dates with a resulting increase in the cost of producing the double-crossed seed. The second procedure requires two dates of planting on only a small scale for the production of the single crosses and permits the planting of both parents at the same time for the seed production of the final double cross. Because of the economic advantage of the second procedure, it is of interest to determine whether the double crosses produced by the two methods differ fundamentally in yield, earliness, variability, or other characters.

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Journal paper J682. Project 163. Received for publication June 20, 1940.

[2]Agent and former Agronomist, respectively, Division of Cereal Crops and Diseases; collaborators, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station.

[3]E = early inbred; L = late inbred.

MATERIALS AND METHODS

All of the inbred lines used in this study were developed in the cooperative corn improvement program of the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Six early-maturing inbred lines and eight late-maturing lines of maize were included in these studies (Table 1). The Four County White lines have white endosperm color, while the remaining inbreds are yellow.

Each double cross was composed of two early and two late inbred lines. Of the three possible double cross combinations among each group of four inbred lines, the (E×E)×(L×L) and one of the (E×L)×(E×L) double crosses were used.

TABLE 1.—*Inbred lines used in the studies and their parent varieties.*

Inbred line	Parent variety
Early Lines	
4Co 31	Four County White
4Co 82	Four County White
4Co 101	Four County White
US 153	U. S. Selection 133
Cl 447	Clark Yellow Dent
GK 646	Golden King
Late Lines	
I 159	Iodent
I 198	Iodent
I 233	Iodent
I 234	Iodent
L 289	Lancaster Surecrop
L 317	Lancaster Surecrop
KB 397	Krizer Bros. Yellow Dent
Os 420	Osterland Yellow Dent

The field plots were arranged in randomized blocks in 1936 and 1937. In 1938 a split plot design was used in which each pair of hybrids composed of the same four inbreds were treated as a unit in the randomization process and then the hybrids within the pair were randomized. Six replications were used in 1936 and 1937, while five replications were used in 1938. Measurements were taken in 1936 on individually tagged plants on silking date, plant height, ear height, and ear weight.[4] In addition, ear length and ear diameter were measured in 1937. Six replications involving 120 plants of each double cross were used for all of the studies of individual plant variability, except for ear weight in 1936 when only three replications totaling 60 plants were used.

EXPERIMENTAL RESULTS

The acre yields of the (E×E)×(L×L) and the (E×L)×(E×L) double crosses for 1936, 1937, and 1938 are shown in Table 2. The analysis of variance for the 3-year period shown at the bottom of the table indicates that the variance ascribed to method of combining was not significant. Similar individual analyses involving the data from each season were computed but are not reported.

[4]For greater detail see Eckhardt, R. C., and Bryan, A. A. The effect of the method of combining the four inbred lines of a double cross upon the yield and variability of the resulting hybrid. Jour. Amer. Soc. Agron., 32:347–353. 1940.

The crop season of 1936 was very hot and dry. The corn crop suffered severely through July with only 0.09 inch of rain and 14 consecutive days with temperatures of 100° F or above (July 4 to July 17). This resulted in low grain yields and high variability. Although the acre yields of the hybrids were low, they averaged 26.9 bushels as compared with 12.1 bushels for the two open-pollinated varieties Golden King and Osterland Yellow Dent. The analysis of variance for 1936 indicated that the variance ascribed to method of combining was not significant.

The season of 1937 was an excellent season for maize production at Ames, and this is reflected in yields of the double crosses. In this season there was a mean difference of 6.0 bushels in favor of the (E×E)×(L×L) combinations. The analysis of variance indicates that this difference is significant.

In 1938, as in 1936, the mean difference in yield between the (E×E)×(L×L) and the (E×L)×(E×L) double crosses was small. As in 1936, the variance ascribed to method of combining was not significant.

The data on the moisture content of the grain at harvest are summarized for the 3-year period in Table 3. Considering the 3-year averages, six of the (E×E)×(L×L) double crosses contained less moisture, one contained more moisture, and one had the same percentage of moisture as the comparable (E×L)×(E×L) double crosses. The analysis of variance shown at the bottom of the table indicates that the variance ascribed to method of combining is not significant.

The "t" tests were computed individually for the data from each season but are not reported. These tests indicated a significantly lower moisture content for the (E×E)×(L×L) double crosses in 1936 but not in 1937 and 1938. Considering the 24 individual comparisons throughout the 3-year period, in 17 of them the (E×E)×(L×L) contained less moisture and in 7 more moisture than the comparable (E×L)×(E×L) double crosses. This method of handling the data yielded a significant value for X^2.

The data on silking date are shown in Table 4. On the basis of the 3-year averages, six of the eight (E×E)×(L×L) double crosses silked earlier than the comparable (E×L)×(E×L) double crosses. The analysis of variance at the bottom of the table shows that the variance ascribed to method of combining is significant. The variances ascribed to pairs, years, and interaction of pairs×method of combining are highly significant. In 17 of the 24 individual paired comparisons the (E×E)×(L×L) double crosses silked earlier than the (E×L)×(E×L) double crosses with which they were compared. This method of analyzing the data yielded a significant value of X^2.

The plant to plant variability of the (E×E)×(L×L) and the (E×L)×(E×L) double crosses was studied with respect to silking date, plant height, ear height, ear weight, ear diameter, and ear length. An analysis of variance was computed for each character of each double cross in 1936 and 1937, the two seasons when individual plant data were taken. The sums of the "within replication" sum of squares were computed for each character studied for the double

TABLE 2.—*Yields of double crosses among early and late lines for 3-year period, 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Yield in bushels			
		1936	1937	1938	Average
Golden King		7.9	53.6	72.5	44.7
Osterland Yellow Dent		16.3	68.6	103.2	62.7
Iowa Hybrid 931	(L 289×Cl 447)×(Os 420×Os 426)	24.9	80.4	97.9	67.7
Iowa Hybrid 939	(I 205×L 289)×(Os 420×Os 426)	32.0	91.7	111.9	78.5
3400	(4Co31×4Co82)×(I 159×L 289)	30.4	91.7	107.5	76.0 } −†
3401	(4Co31×I 159)×(4Co82×L 289)	29.6	91.7	110.6	77.3
3402	(4Co31×4Co82)×(I 159×KB 397)	27.5	90.9	116.1	78.2 } +
3403	(4Co31×I 159)×(4Co82×KB 397)	28.3	87.8	112.4	76.2
3404	(4Co31×4Co101)×(I 159×I 233)	30.0	97.4	116.4	78.3 } +
3405	(4Co31×I 159)×(4Co101×I 233)	27.5	82.9	110.6	73.7
3406	(4Co31×4Co101)×(I 233×KB 397)	32.8	90.2	116.3	79.7 } +
3407	(4Co31×I 233)×(4Co101×KB 397)	32.9	81.9	112.0	75.6
3408	(4Co31×US 153)×(I 233×L 317)	20.3	89.8	109.2	73.1 } −
3409	(4Co31×I 233)×(US 153×L 317)	29.6	84.5	109.5	74.5
3470	(4Co31×4Co82)×(I 159×I 198)	28.6	97.1	113.2	79.6 } +
3471	(4Co31×I 159)×(4Co82×I 198)	32.6	90.1	114.3	79.0
3410	(4Co82×4Co101)×(KB 397×Os 420)	33.3	85.5	109.9	76.2 } −
3411	(4Co82×KB 397)×(4Co101×Os 420)	31.1	90.2	110.5	77.3
3619	(I 234×L 289)×(Cl 447×GK 646)	16.1	78.8	108.5	67.8 } +
3620	(I 234×Cl 447)×(L 289×GK 646)	16.7	64.8	113.6	65.0
Mean yield of all entries		28.0	87.2	111.9	75.7
Mean of (E×E)×(L×L) double crosses		27.4	90.2	112.1	76.6
Mean of (E×L)×(E×L) double crosses		28.5	84.2	111.7	74.8
Difference		−1.1	+6.0	+0.4	+1.8

Source of variation	D.F	Sum of squares	Mean square	F value
Pairs of double crosses	7	687.09	98.16	8.91**
Years	2	59,556.78	29,776.39	2,703.93**
Method of combining	1	36.05	36.05	3.27
Years × method	2	111.10	55.55	5.04*
Pairs × years	14	403.25	28.80	2.62*
Pairs × method	7	100.44	14.35	1.30
Pairs × years × method	14	154.18	11.01	
Total	47	61,048.89		

*Significant.
**Highly significant.
† + indicates (E × E) × (L × L) double cross higher yielding.

TABLE 3.—*Moisture percentage of double crosses among early and late lines for 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Percentage moisture				
		1936	1937	1938	Average	
Golden King		17.7	8.3	11.0	12.3	
Osterland Yellow Dent		18.3	13.0	12.5	14.6	
Iowa Hybrid 931	(L 289×Cl 447)×(Os 420×Os 426)	15.7	11.0	11.2	12 6	
Iowa Hybrid 939	(I 205×L 289)×(Os 420×Os 426)	17.0	14.0	13 4	14.8	
3400	(4Co31×4Co82)×(I 159×L 289)	15.9	10.9	10.8	12.5	+†
3401	(4Co31×I 159)×(4Co82×L 289)	15.3	11.5	11 7	12.8	
3402	(4Co31×4Co82)×(I 159×KB 397)	16.1	11.7	12.0	13.3	+
3403	(4Co31×I 159)×(4Co82×KB 397)	17.9	11.4	13.1	14.1	
3404	(4Co31×4Co101)×(I 159×I 233)	15.7	12 4	13.6	13.9	+
3405	(4Co31×I 159)×(4Co101×I 233)	18.5	12.5	14.0	15 0	
3406	(4Co31×4Co101)×(I 233×KB 397)	15 0	11.9	13 5	13 5	+
3407	(4Co31×I 233)×(4Co101×KB 397)	15.3	12.2	13.4	13.6	
3408	(4Co31×US 153)×(I 233×L 317)	15.6	11.9	11.4	13.0	o
3409	(4Co31×I 233)×(US 153×L 317)	15.7	11.6	11.6	13.0	
3470	(4Co31×4Co82)×(I 159×I 198)	16.1	11.3	10.7	12.7	+
3471	(4Co31×I 159)×(4Co82×I 198)	16.6	11.6	11.4	13.2	
3410	(4Co82×4Co101)×(KB 397×Os 420)	15 2	11.9	13.5	13.5	−
3411	(4Co82×KB 397)×(4Co101×Os 420)	16.0	10.9	12.0	13.0	
3619	(I 234×L 289)×(Cl 447×GK 646)	13.7	10.0	9.9	11.2	+
3620	(I 234×Cl 447)×(L 289×GK 646)	16.3	8.5	10.7	11.8	
Mean of all entries		15.9	11 4	12.1	13.1	
Mean of (E×E)×(L×L) double crosses		15.4	11.5	11.9	12.9	
Mean of (E×L)×(E×L) double crosses		16.5	11.3	12.2	13.3	
Difference		+1.1	−0.2	+0.3	+0.4	

Source of variation	D/F		Sum of squares		Mean squares	F value
Pairs of double crosses	7		30.72		4.39	7.02**
Years	2		191.73		95.86	153.35**
Method of combining	1		1.69		1.69	2.70
Years×method	2		3.21		1.60	2.57
Pairs×years	14		12.39		.63	
Pairs×method	7	35	2.91	21.88		
Pairs×years×method	14		6.56			
Total	47		249.28			

**Highly significant.
†+indicates lower moisture percentage in (E×E)×(L×L) double cross.

TABLE 4.—*Mean silking data (days after June 30) of double crosses among early and late lines for 3-year period 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Days after June 30				
		1936	1937	1938	Average	
Golden King		23.47	19.61	23.00	22.03	
Osterland Yellow Dent		30.72	28.18	24.67	27.86	
Iowa Hybrid 931	(L 289×Cl 447)×(Os 420×Os 426)	29 22	26.71	24.67	26.87	
Iowa Hybrid 939	(I 205×L 289)×(Os 420×Os 426)	29.73	27.00	23.67	26.80	
3400	(4Co31×4Co82)×(I 159×L 289)	26.55	25.05	24.33	25.31	+†
3401	(4Co31×I 159)×(4Co82×L 289)	30.00	26.49	24.67	27.05	
3402	(4Co31×4Co82)×(I 159×KB 397)	29.43	26.88	24.33	26.88	+
3403	(4Co31×I 159)×(4Co82×KB 397)	30 72	26.52	24.67	27.80	
3404	(4Co31×4Co101)×(I 159×I 233)	26.42	25.53	23.33	25 09	+
3405	(4Co31×I 159)×(4Co101×I 233)	27.81	27.64	24.67	26.70	
3406	(4Co31×4Co101)×(I 233×KB 397)	26.70	24.57	22.67	24.31	−
3407	(4Co31×I 233)×(4Co101×KB 397)	25 25	22.89	23.33	23.82	
3408	(4Co31×US 153)×(I 233×L 317)	29 84	26.19	24.00	26.68	−
3409	(4Co31×I 233)×(US 153×L 317)	27.32	23.48	23.00	24.60	
3470	(4Co31×4Co82)×(I 159×I 198)	27.82	24 93	24.00	25.58	+
3471	(4Co31×I 159)×(4Co82×I 198)	28 72	26.86	24.67	26.75	
3410	(4Co82×4Co101)×(KB 397×Os 420)	26.24	23.79	22.33	24.12	+
3411	(4Co82×KB 397)×(4Co101×Os 420)	26 96	23.29	23.00	24.42	
3619	(I 234×L 289)×(Cl 447×GK 646)	27.47	24.98	24.00	25.48	+
3620	(I 234×Cl 447)×(L 289×GK 646)	29.21	26.63	25.33	27.06	
Mean of all entries		27 84	25.36	23.90	25.70	
Mean of (E×E)×(L×L) double crosses		27.56	25.24	23.62	25.48	
Mean of (E×L)×(E×L) double crosses		28.25	25.48	24.17	25.97	
Difference		+0.69	+0.24	+0.55	+0.49	

Source of variation	D F	Sum of squares	Mean square	F value
Pairs of double crosses	7	44.81	6.40	10.78**
Years	2	127.33	63.67	107.24**
Method of combining	1	3.39	3.30	5.71*
Pairs × method	7	18.05	2.58	4.34**
Pairs × years	14	11.23		
Years × method	2 } 30	.67 } 17.81	.59	
Pairs × years × method	14	5.91		
Total	47	211.39		

*Significant.
**Highly significant.
†+ indicates earlier silking date for (E × E) × (L × L) double cross.

crosses of the formula (E×E)×(L×L) and for those of the formula (E×L)×(E×L). The ratio of these terms provided an F value that was used as a measure of the relative variability of the two classes of hybrids. The F values for the characters studied are shown in Table 5.

The lower variance for the (E×E)×(L×L) double crosses in silking date was significant in 1936 and highly significant in 1937. The variances in 1936 were approximately 2.5 times as great as in 1937, presumably because of the drouth conditions in 1936.

TABLE 5.—*F values computed from the variances of the (E×L)×(E×L) and the (E×E)×(L×L) double crosses.*†

Year	Silking date	Plant height	Ear height	Ear weight	Ear diameter	Ear length
1936	1.15*	1.01	1.15*	1.21**	—	—
1937	1.26**	1.21**	1.16*	1.25**	1.14*	1.36**

*Significant (5% level).
**Highly significant (1% level).
†An F value greater than 1.00 signifies a lower variance for the (E×E)×(L×L) group.

There was no significant difference in variance between the (E×E)×(L×L) vs. (E×L)×(E×L) groups for plant height in 1936, but the lower variance for the (E×E)×(L×L) group was highly significant in 1937. The plant height variances in 1937 were about half those of 1936.

Variance for ear height was significantly lower in the (E×E)×(L×L) group in 1936 and 1937.

The lower variance for the ear weights in the (E×E)×(L×L) double crosses was highly significant in both 1936 and 1937.

The ear diameter variance for the (E×E)×(L×L) group was significantly less in 1937 than for the (E×L)×(E×L) group and the lower variance for ear length in the (E×E)×(L×L) group was highly significant.

The (E×E)×(L×L) double crosses had 18% less variance in silking date than (E×L)×(E×L) double crosses over a 2-year period and this difference was highly significant. This indicates that more uniformity in time of flowering can be gained by combining inbreds of the same relative maturity in the same single cross.

In no case was the combined variance of the (E×L)×(E×L) double crosses less than that for the (E×E)×(L×L) double crosses.

It is appreciated that on the basis of theory these differences in plant to plant variability will be reflected in the variability of the plot means of the crosses produced by the two methods of combining the lines. It is felt, however, that any influence of this sort that may have been carried over into the plot means is too minor to affect seriously the reliability of the analyses of variance reported in Tables 2, 3, and 4.

DISCUSSION

The double crosses used in these studies involved a total of six early lines and eight late lines. Three of the early lines may be assumed to be genetically similar, as they came from Four County White. Likewise, four of the late lines may be assumed to be genetic-

ally similar, as they came from Iodent. The remaining lines in each maturity group are of other varietal origin.

Six of the eight pairs of double crosses each involve two of the three lines of Four County White, namely, 4Co31, 4Co82, and 4Co101. Thus there is a certain amount of varietal influence associated with the influence of the parental differences in seasonal requirements in these crosses. The effect of varietal similarity in reducing variability has been demonstrated by the writers.[5] In four of the six pairs of hybrids involving two lines from Four County White, the combination using both Four County White lines together in one parental single cross was most productive over the 3-year period. In the other two pairs of hybrids the combination involving the two Four County White inbred lines in one parent yielded only slightly less than the other member of the pair.

Two of the eight pairs of hybrids involve inbreds from four varieties, four of them involve lines from three varieties, and the remaining two pairs of hybrids involve lines from only two varieties. The conclusions of the same writers that the higher yielding double cross involving two inbred lines from each of two varieties was usually produced by combining the two single crosses, each of which contained the two lines from the same variety, should hold for the last two cases. In both cases, Iowa Hybrid 3404 vs. 3405 and 3470 vs. 3471, the double crosses of the formula $(A\times B)\times(Y\times Z)$[6] had the highest yield.

Although a certain amount of varietal effect is confounded with the effect of differences in seasonal requirements, it is felt that the results obtained represent what may generally be expected from hybrids involving early-maturing and late-maturing lines. In most cases of this kind it would be expected that, although the lines in each maturity group might be from different varieties, they would be more similar genetically than those of the different maturity groups.

The variability studies indicate that greater uniformity in many characters can be obtained by combining the inbreds $(E\times E)\times(L\times L)$. Other things being equal, most farmers desire a uniform hybrid, and by combining the inbreds $(E\times E)\times(L\times L)$ silking date, ear height, ear length, ear diameter, and ear weight were significantly less variable than when the inbreds were combined $(E\times L)\times(E\times L)$.

It is reasonable to believe that this relationship would also hold for moisture content of ear corn at time of harvest. A uniform moisture content at harvest would enable the seedsman to dry his corn to a safe uniform level. He could be more confident that a moisture test would reveal the moisture condition of all the ears and not be an average of wet and dry corn, thus the danger of wet pockets with a consequent injury by organisms or low temperatures would be obviated.

There seem to be definite advantages in the production of superior hybrid seed corn from the practice of utilizing inbred lines of similar maturity in the same single-cross parent. The one big disadvantage of this practice arises from the fact that the resulting parental single

[5]*Op. cit.*
[6]A and B = inbreds from a variety; Y and Z = inbreds from a different variety.

crosses may differ materially in flowering date. Different dates of planting, applications of a phosphate fertilizer to the later single cross, using the earlier single cross as seed parent, or various combinations of these may be used to overcome dissimilar flowering times.

SUMMARY

Experiments were designed to test the best method of combining two early (E) and two late (L) inbred lines of maize. There were no consistent differences in yield between the (E×E)×(L×L) and the (E×L)×(E×L) double crosses.

Variances for silking date, ear height, ear weight, ear diameter, and ear length were significantly less for the (E×E)×(L×L) double crosses.

THE RESPONSE TO FERTILIZERS OF SOILS OF THE BLACKLAND PRAIRIE SECTION OF TEXAS AS DETERMINED BY THE TRIANGLE SYSTEM[1]

J. E. ADAMS, H. V. JORDAN, AND P. M. JENKINS[2]

THE Blackland prairie section of Texas includes some of the most important agricultural soils of the state. An outline of the area, which covers approximately 11,000,000 acres, is shown in Fig. 1. Although complete descriptions of the soils used in this work have been given by Carter (1),[3] the principal characteristics are given here as of importance to the response they show to fertilizers.

The soils of the Houston series are dominant in the area. They are productive, brown to black, highly colloidal clays calcareous throughout the profile, and with a granular surface layer. The eastern margin of the section is composed of soils of the Wilson and Crockett series. These soils vary from very fine sandy loams to clays in texture, gray to black in color, and they are moderately acid to neutral in the upper layers. The Wilson soils have dense, compact subsoils, with the surface soil tending to crust, and in general are not as productive as those of the Houston series.

Within certain areas of Houston black clay of smooth topography the soil retains the physical characters of the Houston, but it is not calcareous in the upper horizons. This latter feature makes such areas comparable with the Wilson rather than with the Houston series. Although such areas are not extensive, they have been classified in recent years as of the Hunt series. Areas of this soil have been mapped in Hunt County (7).

The variations in texture, reaction, and productivity between the soils of the Houston and the Wilson series are reflected in their chemical composition. Fraps and Fudge (2) have shown that Houston black clay, as compared with Wilson clay loam, contains 0.125 vs. 0.105% total nitrogen; 0.081 vs. 0.048% total P_2O_5; and 0.94 vs. 0.82% total K_2O. The active P_2O_5 content of the Houston is 109 p.p.m. as compared with 38 p.p.m. for the Wilson soil. The active K_2O is also greater in concentration for the Houston black clay, the values being 317 vs. 216 p.p.m. These data for the surface horizons indicate that the Houston soil is the more productive. Although no chemical data are shown for the Hunt soils, they would appear to be intermediate in fertility.

EXPERIMENTAL

Few data were available regarding the response of these soils to fertilizers when these experiments were begun in 1928. The experi-

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[1]Contribution from the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication June 3, 1940.

[2]Soil Technologist in Charge of the Soil Fertility Cotton Root-Rot Investigations at Austin, Texas; Associate Soil Technologist, and Assistant Agricultural Aid, respectively. The work was under the general supervision of J. J. Skinner, in charge of cotton soil and fertilizer investigations.

[3]Numbers in parenthesis refer to "Literature Cited", p. 663.

FIG. 1.—Outline of the Blackland prairie section of Texas. The dark areas represent the soils of the Wilson and Crockett series and the light show those of the Houston series.

ments were located on representative areas of Wilson clay loam, Hunt clay, and Houston black clay at various points in the Blackland section. The triangle system, as adapted to fertilizer investigations by Schreiner and Skinner (5), was used in these tests. This particular design allows comparisons among 21 fertilizers each of which carries 15% total plant food, as shown in Fig. 2. All 21 of the ratios were used in the experiments conducted on Wilson clay loam, while selected ratios representing key points in the triangle, namely, Nos. 1, 5, 8, 9, 12, 13, 14, 16, and 21, were used on the Hunt and Houston soils. In most cases the fields were in cotton for several years previous to the beginning of the experiments.

In all experiments previous to 1931 the fertilizers were applied in freshly opened furrows and bedded on at least 10 days before plant-

N

21
15-0-0

15 — 20
12-3-0 12-0-3

10 — 14 — 19
9-6-0 9-3-3 9-0-6

6 — 9 — 13 — 18
6-9-0 6-6-3 6-3-6 6-0-9

3 — 5 — 8 — 12 — 17
3-12-0 3-9-3 3-6-6 3-3-9 3-0-12

P_2O_5 1 — 2 — 4 — 7 — 11 — 16 K_2O
0-15-0 0-12-3 0-9-6 0-6-9 0-3-12 0-0-15

FIG. 2.—Triangular diagram showing the 21 fertilizers, each containing a total of 15% plant food. The upper figure is the triangle number and the lower figure the fertilizer analysis.

ing. The applications were simultaneous with planting in the later experiments, using a combination distributor-planter. No side applications to the growing cotton were made.

Experiments to be continued for a period of years have been initiated since 1935. The Latin square and other randomized plat designs have been used to test fertilizers indicated for these soils by the triangle tests. Data published for the Wilson soil (3, 4) and current data for the other soils confirm those secured by the earlier work here reported.

RESULTS

ON HOUSTON BLACK CLAY SOIL

Experiments were conducted at six locations during the period 1929 to 1935. The period for a particular test varied from two to four years. The plat treatments were the same from year to year and cotton was grown each year. Averages of the data for 20 individual tests are available for study. The rate of application was 600 pounds per acre for each of the nine selected analyses.

The average increases in yield of seed cotton per acre are given in Fig. 3. These were obtained where the average yield of unfertilized cotton was 604 pounds per acre. Of the single elements, nitrogen gave the best increase. This increase was 122 pounds as compared with 19 pounds for potash, 0–0–15, and 17 pounds for phosphate, 0–15–0. The

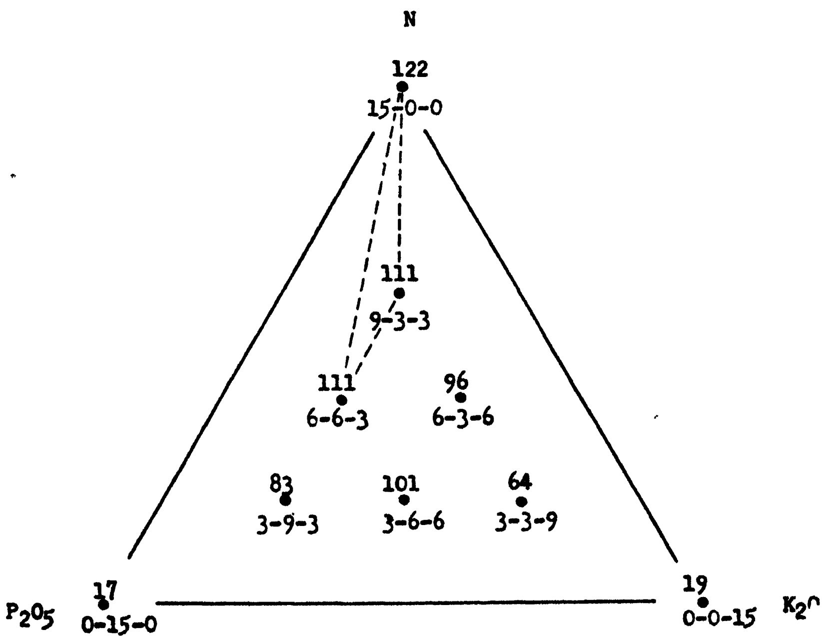

FIG. 3.—Average increases in yields of seed cotton in pounds per acre for the nine selected fertilizers used on Houston black clay soil. The three ratios producing the largest increases are connected by a broken line. The average analysis is 10–3–2.

complete fertilizers, 9–3–3 and 6–6–3, gave increases of 111 pounds each. The general area of the triangle in which maximum increases were obtained is shown by connecting the locations of the 15–0–0, 9–3–3, and 6–6–3 ratios, following the method used by Skinner (6). The average analysis of these three fertilizers is 10–3–2.

The 15–0–0 fertilizer gave the largest increase in 6 of the 20 experiments; the 9–3–3 in 5, the 6–3–6 in 4; the 6–6–3 in 3; and the 3–6–6 in 2.

ON HUNT CLAY SOIL

These experiments were conducted at the U. S. Cotton Field Station, Greenville, Texas, in Hunt County.[4] One field was used from 1928 to 1931 and another from 1932 to 1936 The nine fertilizers used on the Houston soil were also used in these tests on the Hunt clay. The fertilizer was applied at the rate of 600 pounds per acre.

The average increases, which are given as Fig. 4, were obtained where the average yield of unfertilized cotton was 493 pounds of seed

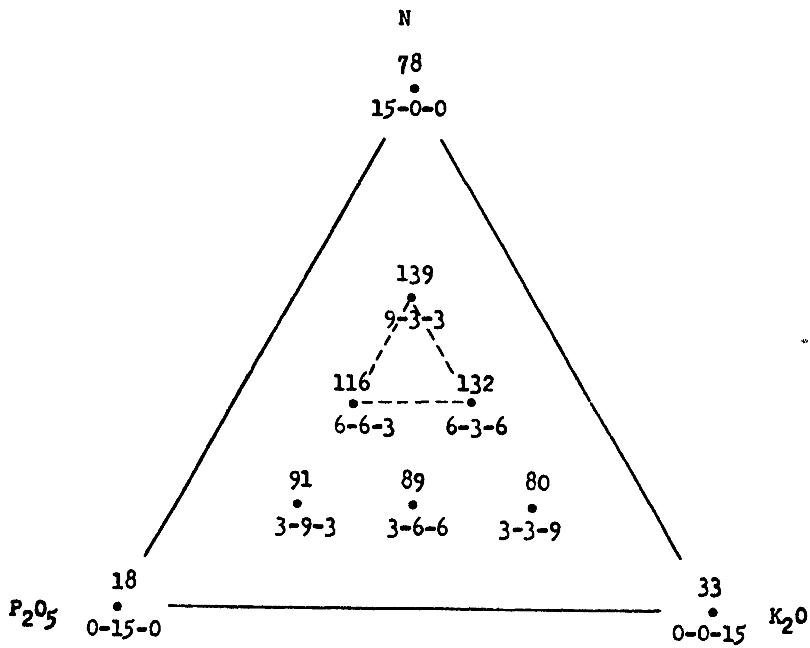

FIG. 4.—Average increases in yields of seed cotton in pounds per acre for the nine selected fertilizers used on Hunt clay soil. The three ratios producing the largest increases are connected by a broken line. The average analysis is 7–4–4.

cotton per acre. Nitrogen alone, as compared with phosphate and potash alone, gave the largest increase, as was the case for Houston black clay. The average increase due to nitrogen was 78 pounds which

[4]Acknowledgment is made of the cooperation of the staff of the U. S. Cotton Field Station, Greenville, Texas, under the supervision of Mr. H. C. McNamara, Superintendent of the Station during the period of the experiment.

is to be compared with 122 for the Houston. The three highest yielding ratios were the 9-3-3, 6-3-6, and 6-6-3. This area, representing the maximum increase, is shown as the small triangle in Fig. 4. The average of the three ratios is 7-4-4 which shows a lowered nitrogen requirement for the Hunt clay as compared to the comparable average of 10-3-2 for the Houston black clay.

In the nine years of this experiment the 9-3-3 ratio was most effective in five years, the 6-6-3 in two, and the 3-6-6 and 6-3-6 ratios in one year each.

ON WILSON CLAY LOAM SOIL

Two locations in Hunt County were used for the experiments on the Wilson soil. One field was on the farm of Richard Craig, near Campbell, and was used from 1928 to 1931. The other was on the farm of A K. Foster, near Greenville, and was used during 1932 and 1933. The 21 fertilizers of the triangle were applied at the rate of 600 pounds in the four-year test and 900 pounds in the two-year test, giving an average application of 700 pounds per acre.

The average yield without fertilizer was 360 pounds of seed cotton per acre. The average increases given in Fig. 5 show that phosphate alone was superior to nitrogen, the increases being 208 and 136 pounds, respectively. Potash, 0-0-15, decreased the yield.

Using all 21 fertilizers, it is seen that the 6-9-0 fertilizer gave the highest average increase. It also gave the highest increase in three of six trials, with 6-6-3, 3-9-3, and 0-15-0 each superior in one year. The 6-9-0 fertilizer was not used, however, on the Houston and Hunt soils. Among the nine ratios common to all experiments, namely, Nos. 1, 5, 8, 9, 12, 13, 14, 16, and 21, the 6-6-3, 3-9-3, and 6-3-6 were the ratios producing the largest increases. The average of the three analyses is 5-6-4. The 5-6-4 analysis is to be compared with the 7-4-4 for Hunt clay and 10-3-2 for the Houston black clay.

DISCUSSION

The comparative productivity of Houston black clay, Hunt clay, and Wilson clay loam soils is reflected in the yields of seed cotton from representative unfertilized plats. The yields were 604, 493, and 360 pounds per acre, respectively. The response of these soils to fertilizers is represented by average increases of the three best of nine fertilizers common to all experiments. The increases are 115, 129, and 244 pounds per acre for the Houston, Hunt, and Wilson soils, respectively. The Hunt clay is intermediate in native productivity with respect to the Houston black clay and Wilson clay loam, also intermediate in response to fertilizers. The increase on Wilson clay loam soil was obtained with an average application of 700 pounds per acre, while the Houston and Hunt soils received 600 pounds of fertilizer per acre.

Not only are there differences in productivity and response to fertilizers among the three soils, but also differences in the kind of fertilizer needed. The dominant need of the Houston soil is for nitrogen, that for the Wilson is phosphate, while the Hunt soil again occupies an intermediate position.

While the largest yields on Wilson clay loam were obtained with a fertilizer in which the content of P_2O_5 exceeds that of nitrogen, other experiments (3, 4) have demonstrated that such fertilizers tend to increase mortality from the cotton root-rot disease. High-nitrogen fertilizers have the opposite effect. For this reason, where root-rot is a factor on Wilson clay loam, a fertilizer such as the 9–3–3 would be preferable. The 9–3–3 ratio has given good increases in yield and has shown some measure of root-rot control as well.

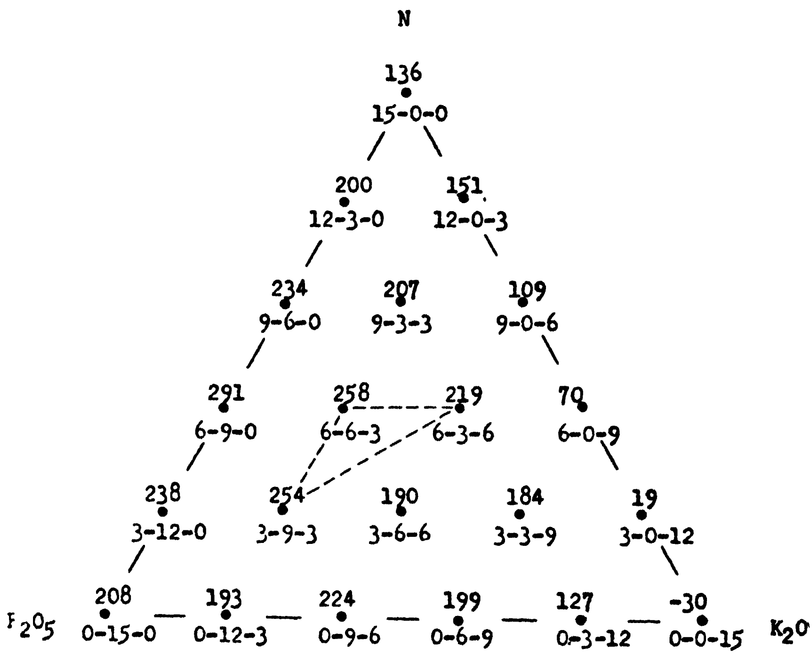

FIG. 5.—Average increases in yields of seed cotton in pounds per acre for 21 fertilizers used on Wilson clay loam soil. For comparison with data for the Houston and Hunt soils the broken line connects the three best fertilizers of the nine selected ratios common in experiments on the three soils. The average analysis is 5–6–4.

The 10–3–2 ratio indicated for Houston black clay is unusual for cotton production and demonstrates the value of the triangle system in orienting fertilizer work.

The nine key ratios can be used to indicate the general area of the triangle in which maximum increases are to be obtained for a particular rate of fertilizer application. The information is more complete, of course, if data are available for all 21 fertilizers. This is shown for the Wilson clay loam. The 12 additional fertilizers used on this soil included one, the 6–9–0, which gave the largest increase in yield. The absence of potash in this 6–9–0 ratio indicates that the use of the full triangle would have changed the values, i.e., 10–3–2, 7–4–4, and 5–6–4, by lowering the potash contents. The relative abundance of

active potash in the Houston and Wilson soils, as reported by Fraps and Fudge (2), also supports this interpretation.

SUMMARY

The effects of fertilizers on the production of cotton are reported for 20 experiments on Houston black clay soil, 9 on Hunt clay, and 6 on Wilson clay loam. These are three of the cotton soils of the Blackland prairie section of Texas. The average yields of unfertilized plats were 604, 493, and 360 pounds of seed cotton per acre for the three soils, respectively.

Using nine key ratios according to the triangle system, the maximum increase in yield, as an average of the three best fertilizers for each soil, was 115 pounds for the Houston, 129 for the Hunt, and 244 for the Wilson soil. The average analysis of the three best fertilizers was 10–3–2 for the Houston, 7–4–4 for the Hunt, and 5–6–4 for the Wilson soil. Additional information on the Wilson soil indicates that the potash content probably could be reduced somewhat for each of the soils.

The study shows gradients in fertility and response to fertilizers as one changes from Houston to Hunt to Wilson soils. The triangle system has been particularly effective in obtaining orienting information concerning the fertilizer needs of the soils of the section. The Latin square and other approved field experimental designs have been used since 1935 to test the fertilizers indicated by the triangle experiments as of greatest importance for an understanding of the fertility of these soils. The data confirm those secured by the triangle system.

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SOLUTION CONCENTRATION AS A POSSIBLE FACTOR INFLUENCING SOIL AGGREGATION[1]

H. E. MYERS AND H. E. JONES[2]

THAT crop plants exert a differential influence on soil tilth has long been recognized and some progress has been made in the elucidation of factors responsible for structural changes resulting from plant growth. Specific factors which have been suggested as contributing to changes in tilth as a result of the growth of crops include root pressure, desiccation, changes in quantity and quality of organic matter, microbial activity, and salt concentration of the soil solution. The possible relation of changes in the salt concentration of the soil solution, especially that of nitrate nitrogen resulting from the microbial decomposition of plant residues, has been suggested by Conrad (1)[3] as an explanation for the differential influence of organic materials on the tilth of soils. He presented evidence which indicates that a decrease in colloidal dispersion accompanies an increase in the concentration of the solution and *vice versa*.

While working in the soils laboratory at the University of Missouri on another phase of the general problem of factors influencing stable aggregate formation, the senior author (2) observed that the addition of calcium sulfate to a sand-colloid mixture in an amount such that the calcium was equivalent to the exchange capacity of the colloid did not increase the percentage of water-stable aggregates synthesized. The experiments reported herein were carried out in order to investigate the influence of salts at greater concentrations on aggregate formation and stability.

MATERIALS AND METHODS

The colloid used was isolated from the heavy B horizon of a soil on the Kansas State College campus. It was transformed to a hydrogen system by electrodialysis. The pulverized clay was a sample from the B horizon of the same soil crushed to pass a 0.105-mm U. S. standard sieve. The quartz sand was also ground to pass a 0.105-mm sieve. It was then digested in concentrated hydrochloric acid and finally washed free of chlorides with distilled water.

Synthesized aggregates were prepared by evaporating either a suspension of 2 grams of H-colloid and 4 grams of quartz sand or a mixture of 5 grams of finely pulverized clay and 5 grams of quartz sand in the presence of varying concentrations of calcium nitrate and sucrose on a steam bath. As the systems approached dryness they were agitated constantly. In all experiments with synthesized aggregates the mixtures were evaporated as quickly as possible after the sucrose and calcium nitrate were added. Usually about 8 hours were required for the drying process. The temperature of the suspension during the period of evaporation was about 75° to 80° C. The heavy clay-quartz sand suspensions with the treatments added were shaken mechanically for 15 minutes previous to being placed on the steam bath.

[1]Contribution No. 305, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication June 11, 1940.

[2]Associate Professor of Soils and Student Assistant, respectively. Suggestions concerning the statistical study of the data were made by H. H. Laude.

[3]Figures in parenthesis refer to "Literature Cited", p. 668.

The natural soil aggregates used were from the A horizon of the Nuckolls silt loam from the agronomy farm. The soil was air dried and then crushed to pass a 4-mm U. S. standard sieve. Treatments were applied in solution to uniform 50-gram samples after which they stood in the laboratory for one week without further addition of water. An equal quantity of distilled water was applied to the untreated samples. Enough water was added to moisten the samples completely. The experiments were completed before the publication of the paper by Waksman and Martin (5) indicating the marked influence of micro-organisms on soil aggregation; therefore, no effort was made to control the microbial population.

The degree of aggregation was determined by wet sieving in distilled water using only the 0.105-mm sieve for the synthetic aggregates, but the 4.0-, 2.0-, and 0.105-mm sieves were used for the natural soil aggregates. The 0.105-mm sieve was selected both because it had been used in previous studies (2) and because all the materials used in the preparation of the synthetic aggregates were either dispersed colloids or substances ground fine enough to pass this size sieve; therefore, all material retained on this screen after wet sieving constituted water-stable synthesized aggregates. The sieves were moved at the rate of 30 strokes per minute through a distance of about 2 inches. The wash water was changed after each washing. All samples were dried uniformly before proceeding with the analysis.

RESULTS AND DISCUSSION

SYNTHESIS OF AGGREGATES

The effect of both sucrose and calcium nitrate on the synthesis of aggregates from both pulverized clay-quartz and H-colloid-quartz systems is shown in Table 1. The data in the third column of figures are also included in the second column wherever possible. The samples were run in groups of three for each treatment. Since the results of only three replications for the 4,000-pound rate are available, they are placed in column III along with the corresponding results from the same run for the other samples. The aggregates were washed for 15 minutes.

To test the significance of the differences between treatments, the data were studied statistically using analysis of variance (4). The results indicate no significant change in aggregation as a result of the treatments since the ratios of the mean squares (between treatments divided by the within treatments) or F values for each column of data were all below the F values required for a 5% level of significance. The standard error of the difference between two mean readings of replicated treatments shown in the table leads essentially to the same conclusion.

While the differences resulting from treatment are not statistically significant, an inspection of the data reveals a few trends that may be of some importance. There seems to be no tendency for either calcium nitrate or sucrose at rates of 1,000 or 2,000 pounds per 2,000,000 pounds to increase consistently the degree of aggregation of the materials used. The data for the calcium nitrate even suggest that possibly this salt interferes to a limited extent with the formation of water-stable aggregates. Excluding the data in column III, which are included in column II, the salt decreased the degree of aggregation six out of six times for rates of 1,000 and 2,000 pounds.

TABLE 1.—*Influence of sucrose and calcium nitrate on the synthesis of aggregates.*

Treatment*	Average percentage of original sample retained on 0.105-mm sieve			
	I Pulverized clay-quartz sand aggregates, av. of 6 samples†	II H-colloid-quartz sand aggregates, av. of 9 samples†	III H-colloid-quartz sand aggregates, av. of 3 samples†	IV H-colloid-quartz sand aggregates, av. of 9 samples‡
Untreated	41.3§	90.2	90.1	73.6
1,000 lbs. sucrose	36.9	88.9	90.2	74.6
2,000 lbs. sucrose	46.3	88.0§	87.5§	72.4
4,000 lbs. sucrose	—	—	95.2	76.1
1,000 lbs. calcium nitrate	31.6	85.3	90.0	68.8
2,000 lbs. calcium nitrate	33.6	87.3	83.8	70.6
4,000 lbs. calcium nitrate	—	—	93.0	78.9§
Ratio of mean squares, F values	0.99	1.11	1.47	1.02
F value required for 5% level of significance	2.78	2.61	2.92	2.27
Standard error of difference between 2 mean readings of replicated treatments	8.37	2.45	5.0	4.69

*Rate of application as pounds per 2,000,000 pounds dry material.
†Not moistened previous to analysis.
‡Moistened previous to analysis.
§Average of one less sample than the indicated number.

The 4,000-pound rate for both sucrose and calcium nitrate tended to increase slightly the degree of aggregation in all four cases. Since the rates at which the calcium nitrate was used are larger than the variation to be expected in the nitrate concentration of a solution of a normal soil, it appears that an increase in the concentration of the soil solution due to biological activity would not directly favor an increased percentage of water-stable aggregates. Recent data by Peele (3) indicate no increase in the degree of aggregation as a result of increasing the concentration of the soil solution with inorganic salts. That the concentration of the soil solution through its influence on root growth might be a factor in aggregate formation is within the realm of possibility.

While it might be possible for these dissolved materials to influence the stability of the aggregate cement, it should be recognized that calcium nitrate and sucrose are not water-resistant cements. In the experiments conducted to obtain the data in Table 1, little opportunity was given for microbial decomposition of the added sugar since the samples were set on a steam bath after all the systems were prepared. However, since 1 to 1½ hours were usually required to set up the mixtures, some decomposition probably did occur before the systems were placed on the steam bath. It is interesting to note that

for equal rates of application the sucrose caused a slightly higher degree of aggregation than did the calcium nitrate. The only exception to this generalization is for the 4,000-pound rate in the H-colloid-quartz system moistened before the analysis.

It is also interesting to note that while moistening previous to analysis resulted in a lower percentage of retained material than when the samples were unmoistened, the relative differences between treatments remained nearly the same.

STABILITY OF NATURAL SOIL AGGREGATES

The influence of sucrose and calcium nitrate at various rates on the stability of naturally occurring soil aggregates is shown by the data presented in Table 2. The aggregates were washed for 30 minutes. The differences between treatments are small, but each treatment did increase slightly the percentage of aggregated material coarser than 0.105 mm. The percentage retained on each of the 4-mm and the 2-mm sieves was always less than 0.2. Statistical analysis, using analysis of variance, indicates that the differences between treatments are insignificant. The ratio of the mean squares (between treatments divided by the within treatments) was 0.36, while for a 5% level of significance a ratio of at least 2.76 is required. Likewise the standard error of the difference between two mean readings of replicated treatments indicates no significant difference from treatment. The slight increase in the degree of aggregation as a result of both sucrose and calcium nitrate additions possibly may be explained on the basis of increased microbial activity since the samples were moistened and then left uncovered and undisturbed in the laboratory for one week. A study of other samples handled in a similar manner indicated that after 8 hours the material had returned to a state of near air dryness.

TABLE 2.—*Influence of sucrose and calcium nitrate on the stability of natural soil aggregates.*

Treatment*	Percentage of original sample coarser than 0.105 mm, av. of 6 samples
Untreated	31.38
500 pounds sucrose	35.48
1,000 pounds sucrose	33.82
500 pounds calcium nitrate	33.26
1,000 pounds calcium nitrate	34.22
Ratio of mean squares, F value	0.36
F value required for 5% level of significance	2.76
Standard error of difference between 2 mean readings of replicated treatments	3.7

*Rate of application as pounds per 2,000,000 pounds dry material.

CONCLUSIONS

The data presented suggest that the direct effect of both sucrose and calcium nitrate at the concentrations of 500 to 2,000 p.p.m. is to cause no significant improvement either in the synthesis of aggregates

or in the stability of naturally occurring soil aggregates. This does not preclude the possibility of an indirect favorable effect as a result of stimulated plant growth or increased microbial activity over a longer period of time.

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SAGEBRUSH-GRASS RANGE SAMPLING STUDIES: SIZE AND STRUCTURE OF SAMPLING UNIT[1]

JOSEPH F. PECHANEC AND GEORGE STEWART[2]

SAMPLING is an ever-existent problem in range research. The evaluation of the effect of experimental range practices on range forage production, the determination of the extent to which vicissitudes of climate influence plant growth, and studies of relationships between plant cover and intensity of erosion require measurement of vegetation. But it is seldom economically possible or practically desirable to observe, measure, or harvest the herbage from every plant on a range area. Usually some method of sampling is resorted to whereby data taken on a small fraction of the area are assumed to represent the whole. From these data are derived the mean or average ($\bar{x}$) as an estimate of the true area mean, and the standard deviation (s) as an estimate of population variability. Only rarely do either of these two estimates coincide with the true value. Provided that both estimates are representative, however, the standard error of the mean, $s/\sqrt{n}$, furnishes the necessary information for determining the probable range of difference between the true mean and the estimated mean, that is, the sampling error.

Theoretically, sampling error may be used to set up fiducial limits (7, pp. 200–1), (14, p. 62)[3] within which the true mean might lie. Thus used, odds would be 19 to 1 (fiducial probability, 95%) that the population mean lies between the 5% limits, or that there are only 5 chances in 100 that it will fall beyond these limits. The unbiased estimate of the standard deviation is additionally useful for predicting the approximate sampling percentage needed on other similar areas to secure a mean with an allowable range of error.

In any study of sampling two aspects must be considered, *viz.*, representativeness and accuracy. Statistically, a sample may be considered as representative if estimates derived from the sample values tend in repeated samplings to give the corresponding population values (2). This representativeness is attained only when each individual of the population is given an even chance of being included in the sample. Accuracy of sampling is affected by method of sampling unit placement, by size and structure of the sampling unit, and by sampling percentage.

Efficient prosecution of range investigations depends on both representativeness and accuracy of sampling. Value of data from well-designed experiments may be seriously impaired by inadequate sampling intensities; costs of sampling may be increased unnecessarily by inefficient plot size or structure, or through lack of care in planning; or the validity of conclusions may be subject to question if the estimates lack representativeness.

[1]Contribution from the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. This study was conducted in cooperation with the Bureau of Animal Industry, U. S. Dept. of Agriculture, at the U. S. Sheep Experiment Station, Dubois, Idaho. Received for publication June 11, 1940.

[2]Associate Forest Ecologist and Senior Forest Ecologist, respectively.

[3]Numbers in parentheses refer to "Literature Cited", p. 682.

Much has been learned of the conditions necessary to secure representative and accurate samples. Wishart (16) and Wishart and Sanders (17) have discussed the general problem of sampling for field agriculture. Christidis (1) dealt intensively with shape of plot as an independent factor affecting plot variability. Hudson (11), in population studies of wheat, considered size and shape of sampling unit, restriction of randomization, and other pertinent problems. Comprehensive treatments of the use of analysis of variance for extracting the maximum amount of information from results of sampling have been offered by Yates and Zacopanay (19), and Cochran (2). Cochran's treatise presents the application of clear-cut formulae to results from a single method of sampling to extract information regarding the relative precision of various alternative sampling methods.

In contrast to the sampling advances of agricultural experimentation, no great specific progress has been made relevant to problems of sampling native vegetation. Davies (6) made studies on the natural pasture lands of Australia. Hanson's (9) work on the mixed prairie vegetation of North Dakota is the only available study specifically applicable to western range lands.

It was the purpose of this investigation to conduct a study of sampling, specifically with reference to size and shape of sampling unit, utilizing the principles evolved in agricultural investigations, and testing their applicability to data from the important native sagebrush-grass range type of southeastern Idaho.

EXPERIMENTAL PROCEDURE

Total herbage-yield data of arrowleaf balsamroot (*Balsamorhiza sagittata*) and tapertip hawksbeard (*Crepis acuminata*), secured on an area of native sagebrush-grass range at the U. S. Sheep Experiment Station, Dubois, Idaho, were used for this study. A rectangular area, 100 by 160 feet, slightly less than 3/8 acre, was subdivided into 640 plots, each 5 feet square, the plots being delineated by tightly stretched wire.

In the spring of 1938, before growth began, all accumulated dead herbage was removed from the area. Then in June 1938, at the height of herbage production, herbage on each 5- by 5-foot plot was clipped by hand at the ground level, placed in individual sacks, air-dried, and weighed.

Herbage yield data of each of the two species were used to construct tabular charts showing the yields on the area by each 25-square-foot plot. Using these charts of yields, the efficiency of various sampling unit sizes and shapes was tested, and the value of some sampling methods explored.

Methods of statistical analysis used are those presented by Fisher (8) and Snedecor (14). Terminology[4] is that used by Cochran (2), Hudson (11), and Wishart and Sanders (17).

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[4]To sample the yield of a plot, a number of small areas of the same size and shape are studied in detail. These are called *sampling units*. The sum of these sampling units is called the *sample* of the plot. The total area included in the sample, expressed as a percentage of the area of the plot, is called *sampling percentage*.

Sampling error is given by $s/\sqrt{n}$ which is based upon an infinite population.

FIELD DATA AND THEIR INTERPRETATION

The general aspect of the typically semi-arid sagebrush-grass type (5, 12), dominated by the ever-present sagebrush, is one of apparent but not real uniformity in density and composition.

Yield data of arrowleaf balsamroot and tapertip hawksbeard, the two most important weed species of the sagebrush-grass type, indicate a high degree of variability. The variability of herbage yields of arrowleaf balsamroot (Table 1) is greater than twice that ordinarily encountered in cultivated crops and the variability of tapertip hawksbeard is two-thirds greater than that of balsamroot.

TABLE 1.—*Average air-dry herbage yields and variability of arrowleaf balsamroot and tapertip hawksbeard on 640 5 by 5 foot plots.*

Species	Average yield per plot, grams	Standard deviation per plot, grams	Coefficient of variability, %
Arrowleaf balsamroot	72.7	46.3	64
Tapertip hawksbeard	7.4	7.6	103

Frequency distributions (Fig. 1) of the herbage yields for both species are distinctly non-normal, that of hawksbeard approaching a Poisson distribution in character. Implications of this serious skewness and the effect of different plot sizes and conformations will be discussed later in this paper.

SAMPLING UNIT SIZE AND STRUCTURE AS AFFECTING VARIABILITY

Sampling unit size and structure have been found to play an important part in determining the accuracy of sampling (1, 2, 11). Variability may be expected to decrease with increased sampling unit size, but not in accordance with the expression $s/\sqrt{n}$ which is based on the premise that increase in (n) will be at random from the entire area. This, however, is not obtained by an increase in sampling unit size. Since, in actual practice, variability is reduced less by increasing sampling unit size than by equivalent random replication,

Forms preferred when dealing with sampling from a finite population are $\sqrt{\frac{s^2}{n} - \frac{s^2}{N}}$ and $\sqrt{\frac{N-n}{N} \cdot \frac{s^2}{n}}$, where N is the number of possible sampling units in the area being sampled. When N is exceedingly large and the sampling percentage low, as is the case in most range experiments, sampling errors calculated from $s/\sqrt{n}$ will produce almost identical results with the preferred form and may be used for approximation. Sampling error is usually expressed as a percentage of the mean.

A precise expression for use in determining the number of sampling units needed for an allowable degree of accuracy is $n = \frac{s^2 N}{(s_{\bar{x}})^2(N-1)-s^2}$ where $(s_{\bar{x}})$ is the standard error of the mean that it is desired to secure. But, since no two areas are absolutely identical, for all practical purposes the commonly used formula $n = \frac{s^2}{(s_{\bar{x}})^2}$ will suffice. This latter formula was used in the following analyses.

smaller sampling units are usually more efficient. To provide data for studying the effect of sampling unit size and structure upon variability of the two native range species, yields for each sampling unit 5 by 5, 10 by 10, 20 by 20, 5 by 10, 5 by 20, 5 by 40, 10 by 20, and 10 by 40 feet in size were read from the balsamroot and hawksbeard herbage productivity charts.[5] Variability of yields for each individual plot size was calculated and expressed as variance (s^2). Mean squares,

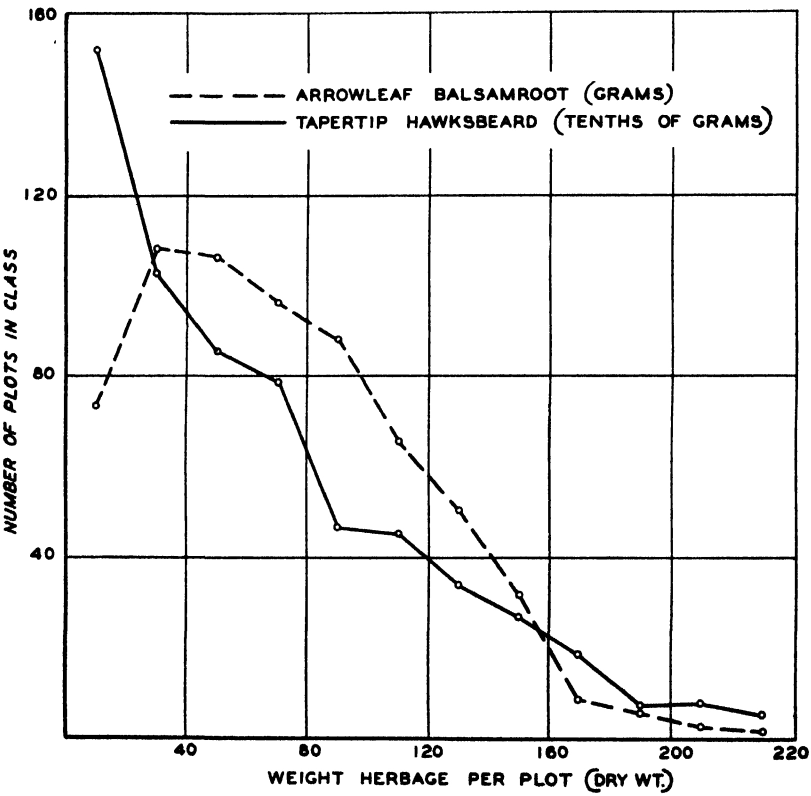

FIG. 1.—Distribution curves of herbage production by arrowleaf balsamroot and tapertip hawksbeard. Plots 25 square feet in area.

in variance, for the different-sized plots were expressed in terms of the 25-square-foot units to make them directly comparable. Efficiency is expressed as invariance, (7, p. 188), the smallest unit, 25 square feet, being considered as contributing 1 unit of information.

For evaluating the effect of size, comparisons were made between units of the same shape in order that any difference in efficiency would be attributable to size alone.

When expressed as invariance (Table 2), the greater efficiency of

[5]Copies of these tabular charts available upon request at the Intermountain Forest and Range Experiment Station, Ogden, Utah.

the smaller units is clearly evident. Square units, 25 square feet in area, are over twice as efficient per unit of area as are units of 100 square feet and five times as efficient as those of 400 square feet. Almost identical ratios exist between rectangular units twice as long as wide and 50 and 200 square feet in area and for units 100 and 400 feet in area with length four times the width. For both balsamroot and hawksbeard, the trends were similar to those found in agronomic experiments.

TABLE 2.—*Relative amounts of information derived per unit of area with different sizes, shapes, and types of sampling units.*

Sampling unit size	Mean square variance*	Invariance†	Units of information per 25 sq. ft.
Balsamroot, Rectangular Compact Sampling Units			
5 feet by 5 feet	2,144.69	0.000466	1.00
10 feet by 10 feet	4,710.30	0.000212	0 45
20 feet by 20 feet	10,723.46	0.000093	0.20
5 feet by 10 feet	2,983.78	0.000335	0.72
5 feet by 20 feet	3,934.24	0.000254	0.55
5 feet by 40 feet	4,561.03	0.000219	0.47
10 feet by 20 feet	6,444 36	0.000155	0.33
10 feet by 40 feet	7,347.15	0.000136	0.29
Hawksbeard, Rectangular Compact Sampling Units			
5 feet by 5 feet	58.10	0.017212	1.00
10 feet by 10 feet	146.35	0.006833	0.40
20 feet by 20 feet	278.63	0.003589	0.21
5 feet by 10 feet	95.09	0.010516	0.61
5 feet by 20 feet	114.71	0.008718	0.51
5 feet by 40 feet	152.98	0.006537	0.38
10 feet by 20 feet	194.21	0.005149	0.30
10 feet by 40 feet	265.30	0.003769	0.22
Balsamroot, Line-plot Sampling Units			
100 square feet in area			
4 subunits spaced 5 feet apart	2,904.21	0.000344	0.74
4 subunits spaced 15 feet apart	2,002.15	0.000499	1.07
4 subunits spaced 35 feet apart	2,013.67	0.000497	1.07
400 square feet in area			
4 subunits spaced 10 feet apart	3,533.13	0.000283	0.61
4 subunits spaced 30 feet apart	3,642.24	0.000275	0.59
Hawksbeard, Line-plot Sampling Units			
100 square feet in area			
4 subunits spaced 5 feet apart	85.78	0.011658	0.68
4 subunits spaced 15 feet apart	69.75	0.014337	0.83
4 subunits spaced 35 feet apart	65.29	0.015316	0.89
400 square feet in area			
4 subunits spaced 10 feet apart	171.54	0.005830	0.34
4 subunits spaced 30 feet apart	140.77	0.007104	0.41

*Mean square on the basis of 25 square foot units.
†Invariance (1/2144.69 =.000466) is the reciprocal of variance.

Increased sampling unit size, it can be seen by comparison of the frequency distributions for the 25- and 100-square-foot compact units (Figs. 1, 2, and 3), is markedly effective in reducing skewness. It may be advisable, in some cases, to utilize this principle, even though it

has been shown by several investigators that the "z" test is valid with rather skewed distributions, because some degree of uncertainty may accompany the interpretation of data from a distribution as skew as that of tapertip hawksbeard. Where species distributions are characteristically Poisson and experimental treatments have produced marked effects, the relation between the mean and variance for different treatments may invalidate the use of analysis of variance without suitable transformations of the data (3); but in dealing with

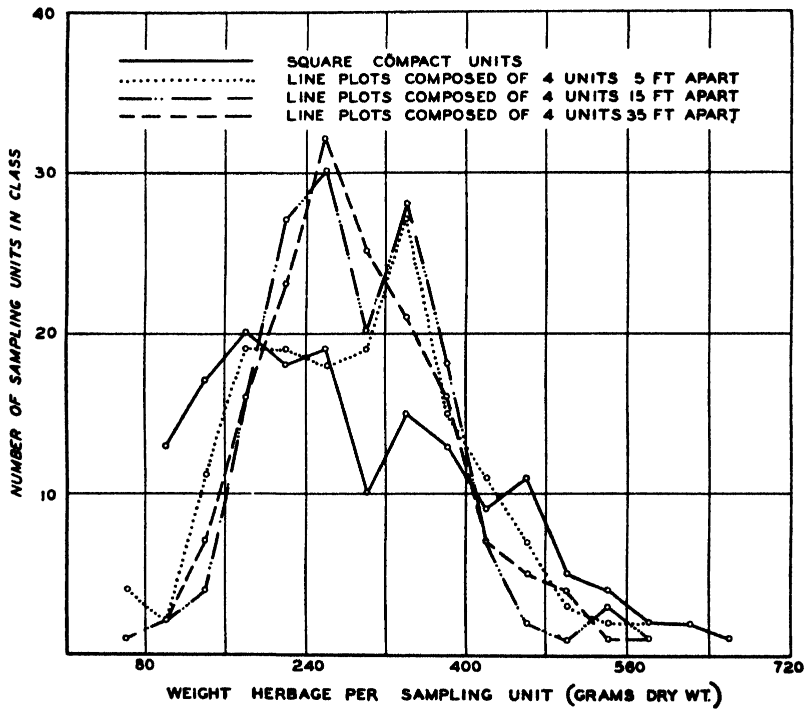

FIG. 2.—Distribution curves of balsamroot herbage production showing influence of type of sampling unit, 100 square feet in area, upon efficiency of sampling.

such distributions, increased sampling unit size has been found to render valuable assistance by decreasing the skewness of badly skewed distributions (6, 11).

Shape of sampling unit as a factor affecting variability was studied by comparing the efficiency of sampling units of the same area but having different dimensions.

In general, with both species, the efficiency of plots in which the length exceeds the width is slightly greater than that for square plots of the same area. Increases in efficiency through the use of long narrow units appears to be slightly more for balsamroot than hawksbeard, there being but little difference in the efficiency of 20 by 20 and 10 by 40 foot units for hawksbeard.

For both species, with 200-square-foot units, increases of length increased the information contributed, units 5 by 40 feet contributing 0.14 and 0.08 unit of information more, respectively, for balsamroot and hawksbeard than the 10 by 20 foot units. Since these limited data tend to follow the same trend found in agronomic experiments and in the studies of Hasel, it may be concluded that long narrow plots tend to be more efficient, though the increases in efficiency may be slight.

LINE-PLOT SAMPLING UNITS

The line-plot, a complex type unit suggested by Wishart (16) and used by Hasel (10), was tested because it may have some peculiarities that adapt it to use in sampling native range vegetation. Wishart (16) states, "The principle being conceded that a number of independently located sampling units are needed to give an estimate of error of sampling, modifications are possible in detail. For example, the sampling unit may be compounded of a number of systematically placed units. This not only saves labor, but is often a definite advantage." Few tests of the complex unit are available with which to judge the soundness of Wishart's assumptions.

Five different types of line-plot sampling units were tested using the uniformity charts. Line-plots 100 square feet in aggregate area composed of four 25-square-foot subunits spaced 5, 15, and 35 feet apart and line-plots 400 square feet in area using four square 100-square-foot units spaced 10 and 30 feet apart were tested. With each type of line-plot, each individual 25-square-foot plot was used but once. Variability in herbage yields are summarized in Table 2.

The 100-square-foot line-plot showed little loss of efficiency as compared with the 25-square-foot unit. With both balsamroot and hawksbeard, efficiency of the line-plot increases with the distance between the subunits, information furnished being about one-third greater when subunits are moved from 5 to 35 feet apart. This may indicate that the more nearly the subunits of a single sampling unit are spaced across the entire area or block being sampled, the more efficient the sampling unit will be. However, the increases from spacing the subunits of the line-plot will be slight when the distance between subunits becomes so great that correlation between adjacent subunits is negligible.

Line-plots 400 square feet in area are but about one-half as efficient as the 100-square-foot line-plots, but this is to be expected since they are compounded from 100-square-foot subunits which were only one-half as efficient as the 25-square-foot subunits (Table 2). With both species line-plots are about twice as efficient as the square sampling units and appreciably more efficient than rectangular sampling units of the same size.

With both balsamroot and hawksbeard, 100-square-foot line-plots decrease the skewness markedly more than 100-square-foot compact units (Fig. 3). As with efficiency and variability, the reduction in skewness becomes greater as the distance between subunits is increased.

Line-plot sampling units, approaching closely the existent method of sampling native range vegetation, would seem to be particularly

adaptable to use in the field. Random selection of the line-plot unit would be much less difficult than that of the compact type unit of similar area. However, the same factors affecting the efficiency of the compact type sampling units will alter the desirability of the type subunit compounded into line-plots, and full cognizance should be given these factors in selecting subunits for use with line-plots.

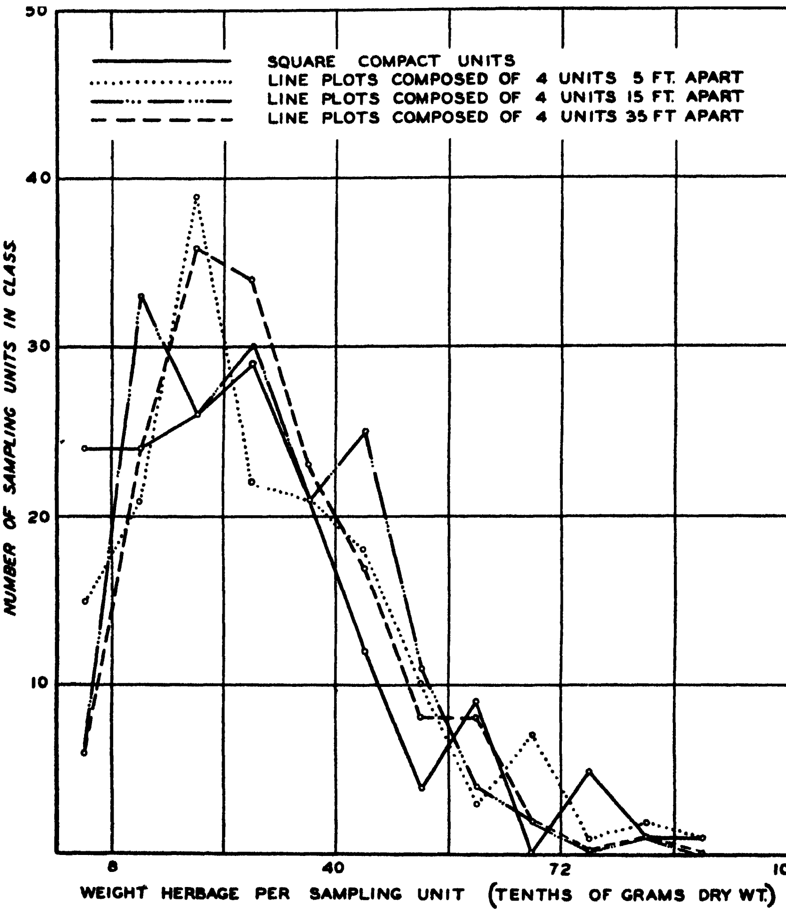

FIG. 3.—Distribution curves of tapertip hawksweed herbage production showing the influence of type of sampling unit, 100 square feet in area, upon efficiency of sampling.

METHODS OF SAMPLING

Sampling aims at two objectives, representative estimates of the mean yield and of the population variance. The certainty with which sampling meets its objectives is dependent upon the method of sampling unit placement. In range studies three general types of placement have been used, *viz.*, typical, systematic, and random, each having it exponents. Each method also has some disadvantages

either in failing to fulfill the objectives of sampling or in difficulty of application in the field.

With typical sampling, several units selected as typical of the whole area are studied intensively, the average being thought to provide information pertinent to the entire area. Since individual units are selected in conformity with the observer's idea of average, it is unlikely that the estimate of error is valid. It has been found that such estimates of the mean yield are apt to portray, in part, the picture in the mind of the observer rather than its true condition. Typical sampling, therefore, provides a poor estimate of population variance and a biased estimate of the mean. Even when the entire population can be inspected, selection based on the judgment of the observer has been found to give samples which are usually biased (4, 18).

Systematic sampling was introduced in an endeavor to eliminate the personal factor inherent in typical sampling. Sampling units spaced at regular intervals along a line or in a gridiron arrangement eliminated the effect of personal bias. Ease of application and the apparent greater reliability of means hastened the acceptance and wide usage of systematic sampling. A fully representative sample, however, only obtained when each individual unit in the area being sampled has an equal chance of being chosen, is not secured by systematic sampling; the estimate of the mean may be representative but biased estimates of variability are usually obtained (2, 10).

A representative sample is secured only when sampling is at random. However, when highly variable material is dealt with, averages calculated from samples secured wholly at random may vary widely. This factor, together with such practical considerations as difficulty in field location and the difficulty of mapping types, has given rise to the wish to obtain some of the benefits of systematic methods. Considerable attention has been devoted to the problem of random sampling in an endeavor to improve accuracy of the means while still retaining a sufficient element of randomness to make the sample representative.

It is interesting to note that the greater reliability of means secured by systematic sampling, to be expected, may not always be attained. From data presented by Hasel (10) means of 56 random within-block samples had a variance of 184 as compared to a variance of 207 for 16 systematic cruises. For random line-plot samples, the population variance between cruises was 222. This differs from the variance of 207 by no more than would result from chance alone, indicating that means secured by random sampling were equal in precision to those secured by systematic sampling.

SUBDIVISION IN RANDOM SAMPLING

Several modifications are possible in the details of random sampling that may promote accuracy. Of these, subdivision offers much promise. Subdivision, the division of the area or population to be sampled into a number of groups so chosen that the species being studied varies little within each group and obtaining at random at least two sampling units from each group, has been found with heterogenous populations to provide more reliable means and smaller

sampling errors. For example, where 40 sampling units are to be used, the area might be subdivided into four blocks and from each block 10 sampling units drawn at random. In analysis, variance would be divided into that between and that within blocks, the latter being used for the calculation of sampling error or population variance. This procedure would result in a substantial reduction in sampling error by eliminating variability between blocks. The object of subdivision is to have the area within groups as uniform as possible, leaving most of the variation to occur between the groups.

The relative merits of subdivision and complete randomization were tested by using the balsamroot and hawksbeard productivity charts, on each of which were located 16 line-plots, 100 square feet in aggregate area with subunits 15 feet apart. For complete randomization, the population variance, to which the values from repeated random samplings would tend, was used. For subdivision, four sampling units were drawn from each of the four blocks, 50 by 80 feet in size, into which the area was arbitrarily divided. With a sampling percentage of 10, and complete randomization, sampling errors of 7.7 and 14.1% are expected, respectively, for balsamroot and hawksbeard.

The mean square variance between samples with subdivided random sampling is substantially less than that expected by strictly random sampling (Table 3). Through subdivision, the information secured was increased 0.29 and 0.22 unit, respectively, for balsamroot and hawksbeard.

TABLE 3.—*Analysis of variance of subdivided random sampling.*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Arrowleaf Balsamroot, Random Sampling, Population Variance			
Between samples	—	————	8,008.58
Arrowleaf Balsamroot, Subdivided Random Sampling			
Between samples	19	139,438.16	7,338.85
Between blocks within samples	60	648,157.38	10,802.62
Between units within blocks (error)	240	1,489,906.82	6,207.95
Total	319	2,277,502.36	
Tapertip Hawksbeard, Random Sampling, Population Variance			
Between samples	—	————	278.80
Tapertip Hawksbeard, Subdivided Random Sampling			
Between samples	19	2,488.58	130.98
Between blocks within samples	60	26,584.84	443.08
Between units within blocks (error)	240	54,797.25	228.32
Total	319	83,870.67	

These increases in accuracy, even on the limited area used, can be secured at the cost of only slight additional planning. On more extensive areas even greater benefits would likely accrue from subdivision and it appears that this method warrants actual field trial.

PRACTICAL CONSIDERATIONS

If the information per unit area were the only criterion of sampling unit efficiency, then the smaller the unit the more efficient it would be, and long narrow compact units would be slightly more efficient than square or round units of the same size. Line-plot sampling units would be particularly promising in efficiency, reduction of skewness, and apparent adaptability for field use. With a constant sampling percentage, however, other practical factors must be considered.

Chief of the practical considerations are the time factors affecting the number of units it is possible to use and the cost of sampling. Some of these factors are:

1. Time spent in walking between sampling units and in locating the permanent markers increases with their distance apart, but not in proportion to increases of unit area. Thus, more time will be required per unit with large than with small units.
2. Time spent in marking out the sampling unit boundary varies nearly directly with the length of the boundary line. With square or rectangular plots of such size that a boundary frame cannot be conveniently used, additional time will be required to lay out the unit and check the corners. In comparison, circular plots require the least time on initial location since they call for the permanent location of only one point, the center.
3. Where measurement of vegetation on the sampling unit is by estimate methods, the time required does not increase directly with the area of the unit except as the number of species may increase with size. Where shrubby species predominate, difficulty in observation is encountered through the use of large units. With clipping methods, time required will vary almost directly with the area.
4. Compilation requires only a slight increase in time per unit for larger units, owing to the slightly larger species list. The labor of analysis of the data from an area increases with the number of individual entries it is necessary to handle. Especially is this the case when a number of statistical analyses is contemplated.

In Table 4 are presented some estimates, based on considerable experience, showing the approximate relative amounts of time required per sampling unit for each of the above procedures as influenced by size of plot. For example, with the 25-square-foot unit, 8% of the total time is spent in walking between sampling units and locating unit markers. The 100-square-foot unit requires 20% more time to complete this operation than the 25-square-foot unit.

Practical considerations of time tend largely to overcome any advantages in statistical efficiency of smaller units. Where estimate methods are used, the relative units of information returned per unit of time are nearly identical for the 25-, 100-, and 400-square-foot units. Since time requirements are estimates, the slight superiority in information per unit of time on the larger units may well be ignored.

TABLE 4.—*Relative time requirements for performing various tasks in the collection and compilation of field data derived with sampling units of different sizes and the effect of time requirement on efficiency.*

Method	Time required in % of total time spent per unit	Effect of sampling unit size on time required, %		
		25 sq. ft.	100 sq. ft.	400 sq. ft.
Walking between units and locating markers:				
Estimate methods	8	100	120	145
Clip methods	2	100	120	145
Laying out boundary of unit:				
Estimate methods	2	100	180	300
Clip methods	1	100	180	300
Securing record on unit:				
Estimate methods	30	100	250	700
Clip methods	81	100	400	1,600
Compilation estimate methods	60	100	110	125
Clip methods	16	100	110	125
Average units of time required per sampling unit:				
Estimate methods	—	1.00	1.54	3.03
Clip methods	—	1.00	3.46	13.22
Units of information per sampling unit (balsamroot)*	—	1.00	1.80	3.20
Information per unit of time:				
Estimate methods	—	1.00	1.17	1.06
Clip methods	—	1.00	0.52	0.24

*From Table 2.

When clipping methods are used, time required per sampling unit varies almost directly with size (Table 4). With clipping methods, therefore, the smaller the sampling unit the greater the efficiency.

Besides the time requirements, points relative to the accuracy of observation must be considered. First, the smaller the unit the greater the error in the study of the less prevalent species. Since secondary species occur less and less abundantly on smaller sampling plots, these species will more often fail to be present in sufficient volume to have a quantitative value assigned them, even where they occur on the unit. Second, when estimate methods are used, it is likely that records on small plots will be taken more carefully than on larger ones where scarce plants or species may be overlooked. With large units there is a tendency for the observer to be disproportionately influenced by the last segment of the unit he views. As Stapledon (15) has stated in favoring the small unit, "it makes you look at it as a whole—you concentrate attention upon it, and thus the greater your number of replications by that much deeper and more intensive your contemplations." With shrubby vegetation smaller size promotes accuracy of observation even more than on open grassland or weed types.

The line-plot sampling unit, when randomized, is particularly easy to locate and use, and is comparable to systematic plot arrangements in this respect. However, all factors affecting time requirements and accuracy of observation apply to the subunits of the line-plot and should be weighed fully in its selection.

Since in selecting sampling unit size, the efficiency from the standpoint of information secured for each unit of area must be considered as well as the reduction of skewness and such practical factors as rapidity, ease, and accuracy of observation, the data presented herein do not completely solve the problem of optimum size and shape.

So many factors are involved which do not permit linear expression that the use of such a formula as Smith (13) found appropriate for determining optimum size of sampling unit is difficult. Experienced judgment, together with acquaintance of the extent and importance of factors that influence optimum size and structure, may be as effective as empirical formulae. Here the problem is to strike a balance between the amount of work, accuracy of observation, and statistical efficiency, for it is often less expensive to collect data from a few large sampling units than from several widely separated small units.

Even though subdivision in random sampling in this study was not tested in the field, it has been shown in other investigations (2, 10, 11, 13) to be a profitable method of increasing sampling accuracy, and often in promoting ease of administration. For this reason, it seems worthy of a trial in sampling native vegetation.

On the basis of this study and consideration of practical factors involved, it is recommended that for sampling native sagebrush-grass range line-plot sampling units, composed of subunits 50 to 100 square feet in area, located at random within subdivisions of the area, be considered for use. Since each study area presents problems of sampling differing somewhat from those elsewhere encountered, it is obvious that results from this study should be directly applied to another area only after a preliminary trial.

SUMMARY

Some problems involved in sampling of native sagebrush-grass range areas were studied at the U. S. Sheep Experiment Station, Dubois, Idaho. On a block of native range, 3/8 acre in area, the herbage of arrowleaf balsamroot (*Balsamorhiza sagittata*) and tapertip hawksbeard (*Crepis acuminata*) was harvested. The area was subdivided into 640 5 by 5 foot plots and the weight of air-dry herbage of each species recorded for each plot. This information was used in testing the efficiency of various sampling unit sizes and shapes and in exploring the influence of subdivision of sampling upon accuracy of the sample.

From a statistical standpoint the smaller the sampling unit the more efficient it is per unit of area. Long narrow sampling units are generally somewhat more efficient than square ones, but the increase may be slight. The line-plot sampling unit, with subunits spaced at systematic intervals along a line, is the most efficient unit studied. However, in selecting a sampling unit for field use, derived from such a

trial as herein conducted, an effective balance must be struck between statistical efficiency and such practical factors as the amount of work and accuracy of observation.

Representativeness, only achieved when the essential element of random selection is included in the sampling procedure, may be conveniently secured in sampling native ranges by use of the line-plot sampling unit.

Subdivision, when tested on uniformity trial data of this study, appears to be a profitable method of improving the accuracy of random sampling on heterogeneous areas.

Subdivided random sampling, using line-plot sampling units, whose subunits are circular plots approximately 50 square feet in area, is recommended for trial in sampling range areas similar to that on which this study was conducted.

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THE VERTICAL DISTRIBUTION OF TOTAL AND DILUTE ACID-SOLUBLE PHOSPHORUS IN TWELVE IOWA SOIL PROFILES[1]

R. W. Pearson, Robert Spry, and W. H. Pierre[2]

VERY few detailed studies of the vertical distribution of either total or dilute acid-soluble phosphorus in soils have been reported, although innumerable analyses of surface layers have been made. Since plants undoubtedly absorb considerable quantities of nutrients from the lower soil horizons, knowledge of the total and easily soluble phosphorus content at different depths in the profile should be useful in estimating the ability of a soil to supply phosphorus to plants. Such investigations, when made with carefully selected and sampled profiles, would also provide valuable data for soil genesis and classification studies.

An examination of the reported determinations of total phosphorus at different depths in soils reveals wide variations in the vertical distribution of this element. Odynsky (5)[3] found a regular decrease in total phosphorus with depth in one of five Alberta soils. In the four other soils studied a minimum occurred in the intermediate layers. Wheeting's (11) results with five Michigan soils show wide differences in the relative amounts of phosphorus found at four depths. In two of the soils the highest percentage was found in the A horizon, in two others in the B horizon, and in one soil the highest percentage was found in the C horizon. Similarly, Stephenson and Chapman (7) found no consistent relation between the phosphorus content of various layers in 11 California soils included in their study. Walker and Brown (3) analyzed samples taken at 0 to 6⅔ inches and 20 to 40 inches. Their results show that larger amounts of phosphorus are present in the surface layer than in the 20- to 40-inch zone.

The fact that the available data show such wide variations in the vertical distribution of total phosphorus may be due, in part, to inadequate sampling; relatively few samples were taken from each profile in most cases, and in a number of studies no samples were taken from the C horizon.

The previously reported investigations of easily soluble phosphorus content at different depths in soils indicate that the amounts present in the C horizon may often be higher than in the upper part of the profile. Alway, McDole, and Rost (1) reported that citric acid-soluble phosphorus increased rapidly to a depth of 6 feet in several soils developed from loess. Below this point constant amounts were found. Phosphorus dissolved by 0.002 N H_2SO_4 was found by Romine and Metzger (6) to be lower in the B than in the A horizons of six out of eight prairie soils studied, and higher in the C than in either the A or B horizons in five of the eight soils. Stephenson and Chapman (7)

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[3]Figures in parenthesis refer to "Literature Cited", p. 695.

found an increase in soluble phosphorus with depth in 4 of the 11 California soils included in their investigation. Since in this study the deepest sampling was from 24 to 36 inches, the C horizon was probably not included. Lohse and Runke (4) reported an increase of soluble phosphorus with depth below the A_2 horizons of virgin Podsolic and Brown Forest soils in Ontario. Odynsky (5) found that phosphorus dissolved by 0.002 N H_2SO_4 increased with depth throughout the profiles of three dark-colored unleached Alberta soils. In two gray severely leached soils a minimum occurred in the B_1 horizon below which the amounts increased to the bottom of the profile. A Marshall silt loam was found by Truog (8) to contain only a trace of dilute acid-soluble phosphorus at a depth of 2 feet, while below this depth the amounts increased rapidly to a maximum in the C horizon.

EXPERIMENTAL

DESCRIPTIONS OF SOILS STUDIED

The samples used in this study were obtained from 12 soil profiles representing 11 soil series which occur in Iowa.[4] These profiles represent three of the great soil groups: The Planosol, Prairie, and Gray-Brown Podsolic soils. The soil types, great soil groups, number of layers analyzed, and profile number are given in Table 1.

TABLE 1.—*Soils used in study.*

Soil type	Profile No	Great soil group	No. of layers analyzed
Carrington silt loam	P-52	Prairie	11
Lucas silt loam	P-3	Prairie	10
Marshall silt loam	P-51	Prairie	12
Tama silt loam	P-27	Prairie	9
Tama silt loam (virgin)	P-100	Prairie	12
Shelby silt loam	P-5	Prairie	11
Waukesha silt loam	P-26	Prairie	10
Grundy silt loam	P-1	Planosol	10
Edina silt loam	P-2	Planosol	13
Muscatine silt loam	P-30	Planosol	8
Fayette silt loam (virgin)	P-32	Gray-Brown Podsolic	13
Weller silt loam (virgin)	P-4	Gray-Brown Podsolic	11

The Shelby and Carrington were developed from glacial till and the Waukesha from alluvial material. All the other soils listed were formed from loess. Only three of these soils, the Fayette, Weller, and Tama (P-100), are represented by virgin profiles.

METHOD OF SAMPLING

Pits were dug to a depth of about 5 feet and samples taken from the pit walls. The surface layers from profiles of soils recently cultivated were taken to a depth of 6 inches. All other samples were taken in layers that were horizons or subdivisions of horizons not thicker than 4 inches. From 15 to 20 samples were taken from each profile, but not all were analyzed, the usual procedure being to analyze alternate layers in the lower horizons.

[4]The authors are indebted to Dr. Roy W. Simonson for collecting the profile samples used in this study.

ANALYTICAL METHODS

For determination of total phosphorus 0.2 gram of finely ground soil was fused with 3 grams of Na_2CO_3. The melt was extracted with hot water, diluted to 500 cc, and phosphorus determined colorimetrically on aliquots of the filtered solution using Truog and Meyer's (10) modification of the Deniges method.

Dilute acid-soluble phosphorus was determined using the method proposed by Truog (9).

The Coleman electrometer was used for pH determinations. One part of soil and 2½ parts of water were shaken for 30 minutes prior to the determination.

RESULTS

The amounts of total and dilute acid-soluble phosphorus and the pH of the layers analyzed are given in Table 2, and the distribution of total and dilute acid-soluble phosphorus within the profiles are presented graphically in Figs. 1 and 2.

TOTAL PHOSPHORUS

An examination of Fig. 1 shows that the amounts of total phosphorus in all the profiles studied decreases with depth from the surface layers to a minimum at from 10 to 30 inches. Below this zone there is in most of the profiles a marked increase with increasing

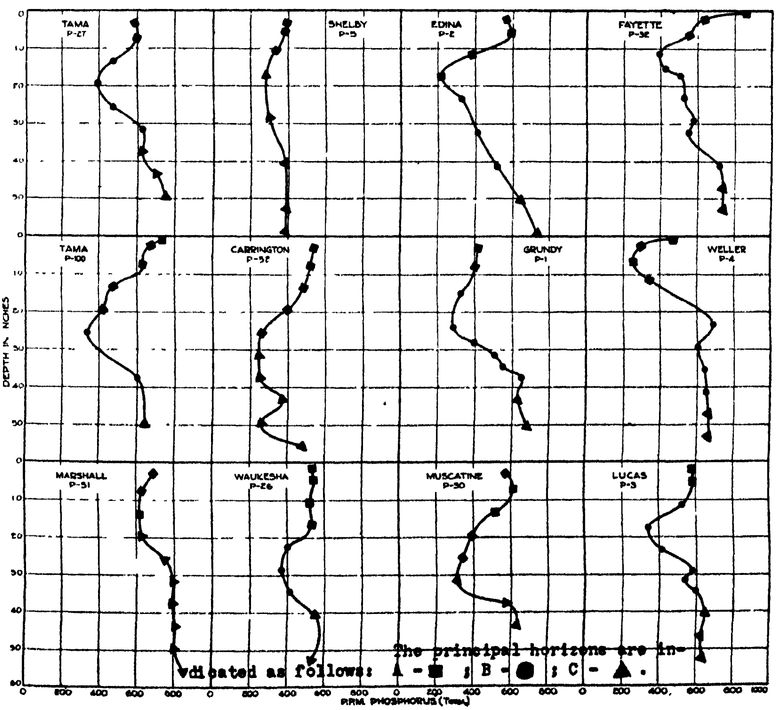

FIG. 1.—Vertical distribution of total phosphorus in 12 Iowa soil profiles.

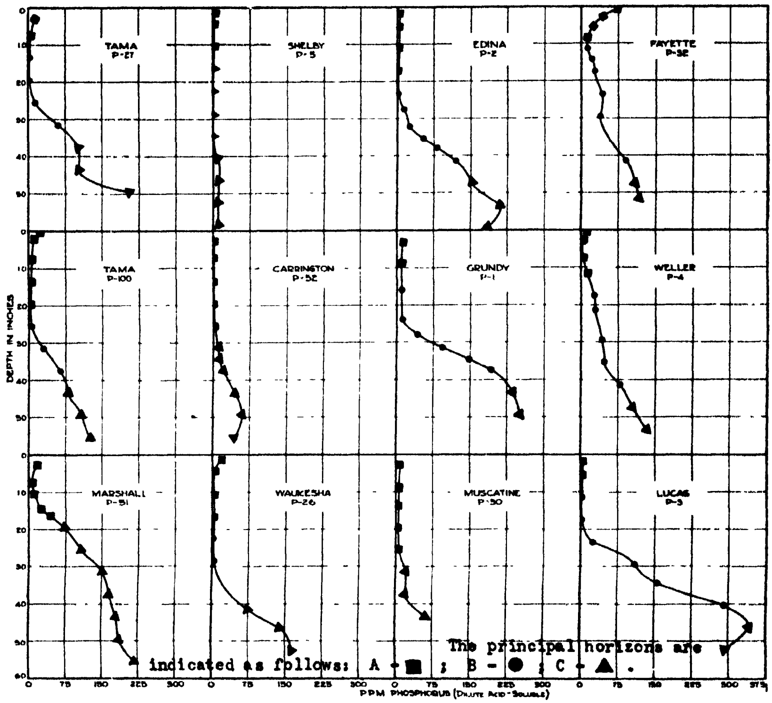

FIG. 2.—Vertical distribution of dilute acid-soluble phosphorus in 12 Iowa soil profiles.

depth to a maximum in the C horizon. There are large differences, however, both within soil groups and between groups, in the rates of change of total phosphorus with depth, in the total amounts present, and in the location within the profiles of horizons in which minimum amounts occur.

Within the Prairie soil group, the two Tama profiles and the Lucas, which contains from 585 to over 700 p.p.m. of phosphorus in the A horizon, show a rapid decrease of total phosphorus with depth to a minimum of about 350 p.p.m. in the upper B horizon. Below this zone the amounts increase, sharply at first and then more slowly, to a maximum of 650 to 750 p.p.m. in the C horizon. In the Carrington and Shelby profiles, on the other hand, the initial decrease with depth is gradual. The quantities found throughout the profiles are much smaller than in the other soils of this group and the amounts present in the C horizon are not quite as high as in the surface layer. The Marshall profile shows tendencies similar to the Shelby in distribution of total phosphorus, although the quantities present in the Marshall are much greater, amounting to 800 p.p.m. in the C horizon as compared to less than 400 p.p.m. in the Shelby.

Marked differences were found between soils of the Planosol group in distribution of phosphorus, although the total amounts present

TABLE 2.—*Total and dilute acid-soluble phosphorus amd pH at various depths in 12 Iowa soil profiles.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Tama Silt Loam (P-27)				
A_1	0–6	0–6	585	11.5	1.9	5.1
A_{11}	6–13	6–9	596	4.4	0.7	5.3
B_1	13–18	12–15	470	3.7	0.7	5.5
B_2	18–24	18–21	386	3.1	0.8	5.4
B_3	24–37	24–27	465	14.5	3.1	5.2
		30–33	622	62.0	9.9	5.3
C_1	37–48	36–39	620	95.0	15.3	5.5
		42–45	699	98.0	14.0	5.8
C	48+	48–51	750	207.0	27.6	5.8
		Tama Silt Loam (P-100)				
A_1	0–1½	0–1½	738	23.2	3.1	7.0
A_{11}	1½–12	1½–3	676	13.9	2.0	6.2
		6–9	631	7.7	1.2	5.7
A_3	12–21	12–15	465	6.3	1.3	5.6
		18–21	408	5.2	1.2	5.4
B_2	21–30	24–27	332	7.1	2.1	5.4
B_3	30–39	30–33		31.9		4.7
		36–39	599	64.1	10.7	5.6
C_1	39–51	42–45		82.6		5.6
		48–51	641	108.0	16.8	5.5
C	51–72	54–57		126.0		5.5
		60–72	684	178.0	26.0	6.2

are comparable. In the Edina, phosphorus decreases rapidly with depth from 595 p.p.m. in the 4- to 7-inch layer to a minimum of only 217 p.p.m. in the lower A horizon, while in the Grundy and Muscatine the decrease is more gradual and the lowest amounts occur at 22 to 26 inches and 30 to 33 inches, respectively. In all three soils maximum amounts of phosphorus occur in the lower part of the C horizon.

The distribution of total phosphorus in the two Gray-Brown Podsolic soils, Fayette and Weller, is quite similar, but the amounts

TABLE 2.—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Marshall Silt Loam (P-51)				
A_1	0–6	0–6	698	17.4	2.4	5.6
A_{11} & A_3	6–18	6–9	634	7.8	1.2	5.6
		9–12		12.4		5.6
		12–15	618	25.3	4.0	5.8
		15–18		43.0		5.8
C_1	18–36	18–21	633	73.0	11.5	5.8
		24–27	759	107.0	14.1	6.2
		30–33	794	151.0	19.0	6.2
C	36–57	36–39	790	166.0	21.0	6.2
		42–45	806	180.0	22.3	6.3
		48–51	800	186.0	23.2	6.3
		54–57	855	217.0	25.3	6.2
		Lucas Silt Loam (P-3)				
A_1	0–7	0–4	583	5.5	0.9	5.2
A_{11}	7–12	4–7	583	4.4	0.7	5.1
B_1	12–16	10–13	524	3.4	0.6	5.0
B_{11}	16–20	16–19	341	3.1	0.9	5.1
B_2	20–29	22–25	416	24.0	5.7	5.4
		28–30	579	109.0	18.8	6.1
B_3	29–41	33–36	599	155.0	25.8	6.4
		39–42	645	291.0	45.1	6.5
C	41–56	45–48	622	340.0	54.6	6.5
		51–54	634	293.0	46.2	6.6

present in the surface layers are widely different. In the Fayette a rapid decrease with depth from 860 p.p.m. in the A horizon to a minimum of 396 p.p.m. at 10 to 13 inches was found. In the Weller the phosphorus content dropped from 468 p.p.m. in the surface to 258 p.p.m. in the 6- to 8-inch layer. Below the zone of minimum phosphorus content there is a general, though irregular, increase to about 700 p.p.m. at the bottom of the profile.

TABLE 2.—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
			Shelby Silt Loam (P-5)			
A_1	0–9	0–3	396	4.7	1.1	5.1
		3–6	385	4.7	1.2	5.1
A_3	9–15	9–12	338	3.3	0.9	4.8
C_1	15–24	15–18	286	Trace		4.9
		21–24		Trace		4.7
C_2	24–36	27–30	298	Trace		5.0
		33–36		Trace		5.0
C_{21}	36–42	39–42	385	8.4	2.1	5.1
C_{22}	42–60	45–48		9.8		5.7
		51–54	390	10.3	2.6	5.5
		57–60	388	10.7	2.7	5.4
			Carrington Silt Loam (P-52)			
A_1	0–6	0–6	543	5.3	0.9	5.2
A_{11}	6–16	6–9	526	3.0	0.5	5.2
		12–15	486	2.5	0.5	5.2
A_3	16–26	18–21	397	2.2	0.5	5.3
		24–27	261	3.8	1.4	5.2
C_1	26–40	30–33	244	9.8	4.0	5.5
		33–36		12.5		5.6
		36–39	251	22.0	8.7	5.6
C	40–57	42–45	371	46.0	12.4	5.7
		48–51	259	60.0	23.1	6.0
		54–57	483	44.0	9.1	6.1

A comparison of soil groups on the basis of total phosphorus distribution is difficult because of the wide differences within the Prairie group, particularly between the soils formed from till and those developed on loess. In general, the Planosol soils studied tend to resemble those of the Prairie group and both groups differ distinctly from the Gray-Brown Podsols.

TABLE 2.—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Waukesha Silt Loam (P-26)				
A_1	0–6	0–3	537	19.5	3.6	4.8
		3–6	545	5.3	0.9	4.8
A_{11}	6–12	9–12	526	4.0	0.7	5.0
A_3	12–21	15–18	533	3.8	0.7	5.0
B_2	21–39	21–24	402	2.5	0.6	5.4
		27–30	373	3.9	1.0	5.2
		33–36	416			5.0
C	39–54	39–42	555	73.8	13.2	5.2
		45–48		140.0		4.9
		51–54	536	162.0	30.2	5.2
		Muscatine Silt Loam (P-30)				
A_1	0–6	0–6	575	8.5	1.4	5.0
A_2	6–20	6–9	618	6.9	1.1	5.2
		12–15	518	6.4	1.0	5.4
		18–21	395	5.8	1.4	5.4
A_3	20–25	24–27	349	6.4	1.8	5.7
C_1	25–32	30–33	307	21.0	6.8	6.5
C	32–48	36–39	576	20.0	3.4	7.0
		42–45	632	62.0	9.8	7.0

DILUTE ACID-SOLUBLE PHOSPHORUS

Fig. 2 shows the vertical distribution of phosphorus soluble in 0.002 N H_2SO_4 in the 12 profiles included in this study. In most of the soils soluble phosphorus decreased slightly with depth to the lower A or upper B horizons and then increased rapidly to the bottom of the profile.

Within the Prairie group the Shelby and Carrington, which were developed from glacial till, contain very low amounts of dilute acid-soluble phosphorus throughout the profile, although there is a slight increase in the lower layers. No layer in either profile to a depth of 3 feet contained more than 12.5 p.p.m. of easily soluble phosphorus, while the highest amount found at any depth was 60 p.p.m. In the Prairie soils formed from loess the increase below the zone of mini-

TABLE 2—*Continued.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Edina Silt Loam (P-2)				
A_1	0–4	0–4	570	6.7	1.1	5.0
A_2	4–11	4–7	595	6.2	1.0	5.1
		10–13	381	5.0	1.3	5.1
A_{21} & A_{22}	11–19	16–19	217	2.8	1.2	5.5
B_2	23–34	22–25	322	3.0	0.9	5.3
		28–31		13.5		5.5
		31–34	409	24.4	5.9	5.6
B_3	34–46	34–37		53.0		5.5
		37–40		82.0		5.8
		40–43	511	121.0	23.6	5.8
C_1	46–56	46–49		153.0		6.1
		49–52	643			
		52–55		206.0		6.2
C	56–65	58–61	738	186.0	25.2	6.2
		Grundy Silt Loam (P-1)				
A_1	0–6	0–6	418	11.1	2.6	5.3
A_3	6–14	6–10	405	8.9	2.2	5.6
B_1	14–18	14–18	327	9.0	2.7	5.9
B_2	18–26	22–26	288	10.0	3.4	6.3
B_{21}	26–30	26–30	397	41.5	10.4	6.1
B_3	30–38	30–33	507	92.5	18.2	6.9
		33–36	551	148.0	26.8	6.7
		36–39	647	192.0	29.6	6.9
C_1	38–48	42–45	630	235.0	37.3	7.0
C	48–56	48–51	685	249.0	36.3	7.0

mum phosphorus content is very rapid and larger quantities are present, ranging, with one exception, from 162 to 340 p.p.m. in the C horizons.

The distribution of easily soluble phosphorus in the Edina and Grundy profiles is quite similar. In both soils the amounts decrease

TABLE 2.—*Concluded.*

Horizon	Depth, inches	Depth of sample, inches	Total P, p.p.m.	Dilute acid-sol. P, p.p.m.	% total P soluble in dil. acid	pH
		Fayette Silt Loam (P-32)				
A_1	0–1½	0–1½	860	74	8.6	6.4
A_2	1½–4	1½–4	639	42	6.5	5.0
A_{21}	4–10	4–7	552	23	4.1	4.5
		7–10		14		4.6
B_1	10–16	10–13	396	12	3.0	4.7
		13–16	421	20	4.7	4.9
B_2	16–19	16–19	507	26	5.1	4.8
B_{21}	19–31	22–25	528	41	7.7	4.8
		28–31	579	38	6.5	4.8
B_3	31–46	31–34	550			5.1
		40–43	718	92	12.8	5.1
C	46–54	46–49	738	109	14.7	5.1
		49–54	732	118	16.1	5.2
		Weller Silt Loam (P-4)				
A_1	0–1½	0–1½	468	13.8	2.9	5.3
A_2	1½–6	1½–4	293	4.5	1.5	5.2
A_{21}	6–10	6–8	258	5.9	2.2	4.5
A_3	10–13	10–13	341	12.4	3.6	4.2
B_2	13–30	16–19		26.0		4.0
		22–25	687	29.0	4.2	3.8
		28–31	601	42.5	7.0	4.0
B_3	30–38	34–37	637	46.0	7.2	4.0
		40–43	649	80.5	12.4	4.1
C	38–58	46–49	661	106.0	16.0	4.5
		52–55	664	136.0	20.4	4.8

slightly with depth to the upper B horizon and then increase very rapidly through the lower layers of the profile to a maximum of over 200 p.p.m. Although the distribution in the upper part of the Muscatine profile is similar to that in corresponding zones in the Edina and

Grundy, the quantities present in the C horizon are much lower, amounting to only 62 p.p.m. It should be noted, however, that the C horizon in the Muscatine occurs at 32 to 48 inches, while in the Grundy and Edina it is found at 48 to 56 and 56 to 65 inches, respectively.

The distribution of dilute acid-soluble phosphorus in the Fayette and Weller profiles is very similar, although the amounts present in the surface of the Fayette are much greater than in the Weller. In both soils there is a pronounced decrease in the A horizon followed by a rather gradual increase to slightly over 100 p.p.m. in the C horizon.

As shown in Table 2, the percentage of total phosphorus soluble in dilute acid decreases slightly from the surface to the lower A or upper B horizon and then increases with depth. These data indicate that a larger percentage of the total phosphorus is soluble in dilute acid in the soils developed from loess than in those formed from till. It is interesting to note that more than 25% of the total phosphorus in the lower horizons of seven of the soils is soluble in dilute acids. In the C horizon of the Lucas this fraction amounted to 54%.

GENERAL DISCUSSION

Total phosphorus in all the profiles studied was found to decrease with depth, after a slight initial increase in several of the cultivated soils, to a minimum which generally occurred in the lower A or upper B horizons. Below this zone the amounts increased with depth to the C horizon, where in a number of cases the highest values were found. The general occurrence of a zone of minimum phosphorus content below the surface layers is possibly the result of absorption by the native vegetation over long periods of time. In this way the concentration of phosphorus in the surface could have been increased at the expense of the underlying layers. However, the surface layers do not contain large enough amounts to account for the phosphorus lost from the lower A and upper B horizons. Erosion may have caused considerable loss from the surface layers of some of the soils, but in others, such as the Grundy, which occur on very flat areas, this seems questionable. Other possible explanations would be variations in the original loess deposits or translocation of phosphorus within the profiles.

The differences between soils in content and vertical distribution of total phosphorus can be attributed to variations in both parent materials and the conditions under which the profiles developed. Thus the soils formed from loess contain larger amounts of phosphorus in the C horizon and generally more in the surface layers than those developed from glacial till, indicating a higher original phosphorus content in the loess than in the till. The dissimilarity between the Gray-Brown Podsolic soils and those of the Prairie and Planosol groups is due primarily to the fact that the former were developed under forest while the latter were formed under grass vegetation. The resulting difference in the location within the profiles of zones of maximum root development may be responsible for variations in phosphorus distribution.

In 9 of the 12 profiles studied the dilute acid-soluble phosphorus was found to increase greatly with depth, after an initial decrease to a minimum in the lower A or upper B horizons. A question immediately arises concerning the form in which this phosphorus could be present to account for its high solubility in the lower part of the profile. There is no consistent relation between the pH and easily soluble phosphorus content of the different horizons. For example, the C horizons of the Muscatine and Grundy soils both have pH values of about 7.0 and the maximum amount of dilute acid-soluble phosphorus in the former is only about one-fourth as high as in the latter. Likewise the C horizon of the Tama (P-27), which has a pH of 5.8, contained 207 p.p.m. of dilute acid-soluble phosphorus or about the same amount as the Grundy.

The work of Heck (2) indicates that calcium phosphates are rapidly dissolved by 0.002 N H_2SO_4, while the more difficultly soluble iron and aluminum phosphates continue to release phosphorus in a number of successive extractions. On the basis of these differences in rates of solution, re-extraction studies have been made on several samples in an attempt to determine the nature of the phosphorus compounds present in the lower horizons. Preliminary results show that large amounts of phosphorus are dissolved by re-extraction. According to Heck (2), this indicates that the large amounts of dilute acid-soluble phosphorus in the subsoils are due to the presence of iron and aluminum phosphates rather than calcium phosphates. It seems questionable, however, that large amounts of iron and aluminum phosphates would be present in the C horizon of soils like Grundy and Marshall that are neutral or only slightly acid in reaction.

Insufficient data are available from field experiments in the immediate vicinity from which the profiles were taken to justify an attempt to relate definitely the dilute acid-soluble phosphorus content of these profiles to crop response. However, it has been found generally true that the Shelby and Carrington soils, which contain the lowest amounts of dilute acid-soluble phosphorus throughout the profile, are among the most responsive to phosphate applications of the soils found in the state. Of course, other soil characteristics, such as the presence of a heavy B horizon, would influence to a considerable degree the use plants could make of available phosphorus present in the C horizon.

Although the data presented indicate that the lower part of the soil profile may play an important part in supplying phosphorus to growing plants, further investigation in the greenhouse and in the field will be necessary before this question can be definitely answered.

SUMMARY

Twelve soil profiles representing 11 soil series which occur in Iowa were selected for a study of the vertical distribution of total and dilute acid-soluble phosphorus. Seven of the soils studied belong to the Prairie, three to the Planosol, and two to the Gray-Brown Podsolic groups. The profiles were sampled in layers that were horizons or subdivisions of horizons not exceeding 3 inches, except the Grundy silt loam which was sampled in part at 4-inch intervals.

Two of the Prairie soils were developed from glacial till and one from alluvial material. The other nine soils were formed from loess.

In all the profiles studied total phosphorus was found to decrease with depth to a minimum between the lower A and upper C horizons. Below this zone, in 11 of the 12 soils, the amounts increased rapidly with depth to the bottom of the profile. In eight of the soils the concentration of phosphorus in the C horizon was more than double that in the lower A to upper B horizons.

The soils developed from till contained much smaller quantities of total phosphorus throughout the profile than those formed from loess. The former contained an average of about 300 p.p.m of phosphorus as compared to 500 to 700 p.p.m. in the latter.

In general, the distribution of total phosphorus in the Planosol soils resembled that in the Prairie soils. The distribution in the Gray-Brown Podsolic soils differed considerably from that in the other groups, particularly in that the zone of minimum phosphorus content occurred nearer the surface.

Dilute acid-soluble phosphorus also decreased with depth to a minimum in the lower A or upper B horizon, and then increased markedly in subsequent layers to a maximum in the C horizon. The content and distribution of dilute acid-soluble phosphorus in the Planosol soils is quite similar to that in the normal Prairie soils developed from loess. In the Gray-Brown Podsolic soils the increase with depth begins at a point nearer the surface and is more gradual than in the Prairie soils formed from loess.

Much larger quantities of easily soluble phosphorus were found in the C horizons of the Prairie soils developed from loess than in those formed from glacial till; the maximum amounts present in the former were generally higher than 200 p.p.m. as compared with less than 60 p.p.m. in the latter.

No consistent relation was found between pH and the dilute acid-soluble phosphorus content of the soils.

In seven of the 12 soils studied more than 25% of the total phosphorus present in the lower layers was soluble in dilute acid, and in one soil 55% was soluble, as compared with 0.94 to 3.63% soluble in the surface layers.

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EFFECT OF TIME OF SEEDING ON YIELD, MILLING QUALITY, AND OTHER CHARACTERS IN RICE[1]

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GROWERS are vitally interested in information on the best date for sowing rice (*Oryza sativa* L.) in order to obtain maximum yields per acre of high milling quality. It is especially important, as has been pointed out (6),[3] to know how new varieties and selections react when sown on different dates.

In response to date of seeding and environment, rice varieties may be grouped as "indifferent" or "sensitive." When sown early in the spring, the "indifferent" varieties head and mature in the summer or early fall, whereas the "sensitive" varieties do not usually head and mature until fall. Jenkins (6) classed the "indifferent" varieties as having a "fixed growing period" able to head and mature during longer photo periods, while the "sensitive" varieties, described by Nelson (10) as having "a marked power of adaptation," head and mature during the shorter fall days. The growth period of all varieties is shortened to some extent when sowing is delayed, but varieties differ in degree of response and this difference in response is heritable and one of the outstanding characteristics of rice varieties. A date of seeding experiment in nursery plots was started at the Rice Branch Experiment Station, Stuttgart, Ark., in 1932 to obtain additional information on the effect of seeding date on the yield, growth, and quality of rice varieties. The results are reported in this paper.

MATERIAL AND METHODS

A total of 15 varieties and selections of rice, sown on four or five dates each season, was tested in 1 to 8 years. Eight varieties were grown each year from 1932 to 1936 and 10 varieties thereafter. The varieties were sown on five dates at approximately 15-day intervals each year from 1932 to 1936. After 1936 the late April seeding was omitted and seedings were made on only four dates.

Most of the varieties grown have been described in the literature. The short-grain varieties, Caloro and Colusa, were described by Jones (8), Acadia by Chambliss and Jenkins (2), and Jones (9) has described briefly the other varieties grown in this experiment, with the exception of Early Rose, Zenith, Arkansas Fortuna, Kameji, and the four hybrid selections.

Early Rose is an early-maturing, medium-grain variety selected by a rice grower in Arkansas. It was grown commercially in Arkansas for a year or two, then discarded. Zenith is an early-maturing, medium-grain variety selected in Arkansas in 1931 from a field of Blue Rose. Arkansas Fortuna is a long-grain variety selected from Fortuna and is the same as Fortuna except that it matures from 7 to 10 days earlier. Kameji is a midseason, short-grain variety.

The four hybrid selections grown were developed at Stuttgart, Ark., from crosses Caloro × Blue Rose, Kameji × Blue Rose, Edith × Fortuna, and Im-

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[3]Figures in parentheses refer to "Literature Cited", p. 706.

proved Blue Rose × Fortuna. They were selected from segregating F_2 and F_3 generations in the material received from the Biggs Rice Field Station, Biggs, Calif. The selections Caloro × Blue Rose (A. H.-29-19)[4] and Kameji × Blue Rose (A. H.-29-128) are midseason, medium-grain types, and Edith × Fortuna (A. H.-28-24) and Improved Blue Rose × Fortuna (A. H.-29-39) are midseason, long-grain types.

The varieties were grown in triplicate, systematically-replicated 3-rod row plots from 1932 to 1936 and in quadruplicate, randomized 3-rod row plots from 1937 to 1939. The standard deviation for grain yields in the systematically replicated plots was computed by the deviation from the mean method as suggested by Hayes (5) and the analysis of variance method for the randomized plots. An average standard error of the mean, in percentage, was computed for each date of seeding. These values were obtained by the formula $1/N \sqrt{a^2+b^2+c^2 \text{——} n^2}$, where N equals the number of values averaged and a, b, c —— n represent the values for the standard error of the mean for each year. An average standard error of the difference for each date of seeding was obtained by multiplying the average standard error of the mean for the years grown by $2\sqrt{2}$.

The yields were recorded after the rough rice was cleaned so as to be comparable to the commercial product. The yield of straw was obtained by subtracting the weight of the threshed grain from the weight of the total crop before threshing. Plant height was measured from the surface of the soil to the tip of the panicle.

Milling quality was determined by means of a Smith shelling device as described by Smith (11) and the separations were made by the method outlined by Boerner, *et al.* (1). The estimated yield of "head rice" and "total rice" was obtained from tables computed by W. D. Smith and his co-workers for that purpose. Smith, *et al.* (12, p. 2) define "head rice" as "milled rice consisting principally of whole kernels." "Total rice" is "head rice" plus all broken grains obtained in the milling process. The yields of "total rice" are not reported because the date of seeding did not seem to influence this character to any great extent.

The results for all factors studied are given in Table 1.

RESULTS

TIME OF MATURITY

Based on the manner in which the varieties reacted when sown on different dates, they are placed in two groups: (a) "Sensitive" varieties that showed a gradual but marked decrease in the number of days required to reach maturity when sown on successively later dates, and (b) "indifferent" varieties that showed a small but less consistent shortening of the growth period as sowing was delayed. Those in group 1 include Caloro, Colusa, Acadia, Supreme Blue Rose, Caloro × Blue Rose (A. H.-29-19), and Kameji × Blue Rose (A. H.-29-128), in which the reduction in the period from seeding to maturity from the first to the last date of seeding was 18 to 26%. Group 2 includes Early Prolific, Early Rose, Zenith, Storm Proof, Arkansas Fortuna, Nira, Edith × Fortuna (A. H.-28-24), and Improved Blue Rose × Fortuna (A. H.-29-39), in which the reduction in the period from seeding to maturity between the first and last or next to the last date of seeding was from 9 to 15%. The first four

[4]Hybrid selection numbers of the Rice Branch Experiment Station, Stuttgart, Ark.

varieties listed in group 2 required a longer growing period for the last date than for the preceding date of seeding.

When sown about the middle of June, Arkansas Fortuna failed to mature in 6 of the 8 years and Nira matured grain in 1939 only. Rexoro is a very late variety (group 2) and not suited for growing in Arkansas but usually matured a fair crop when sown in April. In this experiment it failed to reach full maturity when sown May 15 or later.

In some varieties, including Caloro, Colusa, Acadia, and Supreme Blue Rose, the length of the growing period was much reduced by late seeding and they matured when sown even as late as June 20. Other varieties, including Arkansas Fortuna, Nira, and Rexoro, showed less response to seeding date and did not mature from June sowing every year. Other "indifferent" or less responsive varieties, such as Early Prolific, Zenith, Early Rose, and Storm Proof, matured from June seeding. These results are in general agreement with those reported by Nelson (10), and Jenkins (6).

PLANT HEIGHT

Regardless of the date of seeding, none of the varieties grew so tall that it lodged or so short that it could not be harvested conveniently. The response in plant height to date of seeding differed, however, with the variety.

The varieties in group 1 that showed a gradual reduction in growing period when sown on successive dates also showed a gradual decrease in height from the first to the last date of seeding. The varieties in group 2 that showed a less marked reduction in the growing period were variable in height but, with certain exceptions, showed no consistent reduction in height due to delayed seeding. Edith × Fortuna (A. H.-28-24) and Improved Blue Rose × Fortuna (A. H.-29-39) showed a height reduction similar to that of the varieties in group 1 as did also Arkansas Fortuna, Rexoro, and Nira when they matured from the later dates of seeding.

The varieties that had the greatest shortening of the growth period (group 1) decreased in height in direct relation with the length of the growth period. In some of the "indifferent" varieties (group 2) the plants from the later dates of seeding were often taller than those from earlier seedlings.

All "sensitive" varieties reacted in the same manner with respect to plant height. The plants continued to increase in height until they headed during the shorter fall days; hence, when sown early, they had a longer growth period and were taller than when sown late. The "indifferent" varieties were variable in plant height and sometimes were taller when sown late than when sown early.

STRAW YIELD

Straw yields were obtained during the first 4 years of the experiment. The ratio of grain-straw was obtained by dividing the yield of straw by the yield of grain. A high yield of straw, unless accompanied by a correspondingly high yield of grain, increases the labor of har-

TABLE 1.—*Average growing period, plant height, yield, and milling quality of 15 varieties of rice sown at different dates.*

Variety or hybrid selection	C. I. No.[1]	Years grown	Average date sown	Period from seeding to maturity, days	Plant height, inches	Grain yield per acre		Estimated yield of head rice			Acre yield of straw, lbs.	Straw
						Total, lbs.	Compared with Supreme Blue Rose, %	Per barrel, lbs.	Per acre, lbs.	Difference from average of variety, lbs.		grain ratio
"Sensitive," Group 1												
Caloro	1561–1	1932	Apr. 14	146	47	2,052	106.5	99	1,254	−363	5,995	2.92
		1932	Apr. 28	142	42	2,318	113.2	103	1,474	−143	4,447	1.92
		1932	May 14	131	41	2,525	125.8	107	1,668	+ 51	3,492	1.38
		1932	May 30	120	38	2,516	95.9	107	1,662	+ 45	3,498	1.39
		1932	June 17	108	37	3,159	204.7	104	2,028	+411	4,383	1.39
Colusa	1600	1932–36	Apr. 14	137	40	770[2]	45.5	91	432	−439	3,156	4.10
		1932–36	Apr. 29	126	38	1,121	66.0	92	637	−234	3,350	2.68
		1932–36	May 15	118	37	1,598	92.2	97	956	+ 85	4,102	2.45
		1932–36	May 29	115	37	1,998	112.1	99	1,221	+350	3,910	1.77
		1932–36	June 15	114	36	1,778	120.4	101	1,109	+238	3,942	2.17
Acadia	1988	1937–39	Apr. 22	154	44	1,908	134.2	102	1,202	+ 44	—	—
		1937–39	May 13	143	38	1,697	129.1	99	1,038	−120	—	—
		1937–39	May 31	132	35	1,805	135.9	100	1,114	− 44	—	—
		1937–39	June 20	120	34	2,030	142.7	102	1,278	+120	—	—
Supreme Blue Rose	5793	1932–39	Apr. 17	168	46	1,692	—	98	1,023	+ 44	4,594	2.31
		1932–36	Apr. 29	159	42	1,697	—	92	964	− 15	5,338	3.13
		1932–39	May 15	148	41	1,733	—	98	1,049	+ 70	6,330	3.10
		1932–39	May 30	138	41	1,782	—	97	1,067	+ 88	6,086	2.94
		1932–39	June 17	134	38	1,476	—	87	793	−186	5,676	4.38
Selection Caloro × Blue Rose (A. H.-29-19)	—	1937–39	Apr. 22	152	46	1,877	132.0	100	1,159	− 11	—	—
		1937–39	May 13	139	41	1,962	149.3	101	1,223	+ 53	—	—
		1937–39	May 31	132	38	1,706	128.5	99	1,042	−128	—	—
		1937–39	June 20	121	36	2,075	115.0	98	1,255	+ 85	—	—

Selection Kameji × Blue Rose (A. H.-29-128)	—	1938–39	Apr. 24	150	47	1,904	123.0	99	1,163	+ 40	—	—
		1938–39	May 10	140	42	1,625	128.5	98	983	−140	—	—
		1938–39	May 31	131	39	1,737	119.1	99	1,061	− 62	—	—
		1938–39	June 21	121	36	2,084	130.1	100	1,286	+163	—	—
"Indifferent," Group 2												
Early Prolific	5883	1932–39	Apr. 17	138	43	819[2]	48.4	85	430	−450	3,254	4.41
		1932–36	Apr. 29	130	40	1,377	81.2	85	723	−157	3,812	2.43
		1932–39	May 15	126	41	1,877	108.3	92	1,066	+186	4,930	2.17
		1932–39	May 30	124	42	2,147	120.5	94	1,246	+366	4,661	1.88
		1932–39	June 17	128	41	1,800	122.0	84	933	+ 53	5,175	3.04
Early Rose	—	1932–34	Apr. 13	134	37	1,283	56.0	94	744	−170	2,742	2.14
		1932–34	Apr. 28	124	34	1,170	63.4	91	657	−257	3,191	2.73
		1932–34	May 15	120	35	1,598	74.6	96	947	+ 33	4,430	2.81
		1932–34	May 30	118	37	2,052	88.0	98	1,242	+328	5,151	2.51
		1932–34	June 15	119	34	1,728	116.7	92	982	+ 68	6,382	3.69
Zenith	7787	1933–39	Apr. 17	139	43	891[2]	53.5	90	495	−415	2,688	3.62
		1933–36	Apr. 29	131	41	1,310	82.4	89	720	−190	3,278	2.22
		1933–39	May 15	126	41	2,007	118.6	94	1,165	+255	4,857	1.89
		1933–39	May 30	123	40	2,088	125.7	93	1,199	+289	4,361	1.75
		1933–39	June 17	126	39	1,899	129.4	83	973	+ 63	4,340	2.41
Arkansas Fortuna	—	1932–39	Apr. 17	151	48	1,670[2]	98.7	75	773	+ 60	3,710	2.03
		1932–36	Apr. 29	144	46	1,895	111.7	72	842	+129	3,122	1.58
		1932–39	May 15	141	47	2,187	126.2	69	932	+219	4,616	1.85
		1932–39	May 30	141	44	1,944	109.1	74	888	+175	4,515	2.32
		1932–39	June 17	129	40	441[3]	29.9	48	131	−582	4,891	2.79
Storm Proof	7705	1932–36	Apr. 14	139	45	1,179[2]	63.7	78	568	−207	3,732	3.17
		1932–36	Apr. 29	129	41	1,229	72.4	78	592	−183	4,118	3.00
		1932–36	May 15	123	44	1,854	93.6	82	938	+163	4,777	2.56
		1932–36	May 29	119	45	2,115	103.1	87	1,136	+361	4,661	2.18
		1932–36	June 15	128	43	1,755	116.4	59	639	−136	5,806	3.20

[1]Accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. Agriculture.
[2]Not harvested because of very poor stands in 1936.
[3]Matured grain in 1933 and 1939.

TABLE 1.—*Concluded.*

Variety or hybrid selection	C. I. No.[1]	Years grown	Average date sown	Period from seeding to maturity, days	Plant height, inches	Grain yield per acre: Total, lbs.	Grain yield per acre: Compared with Supreme Blue Rose, %	Estimated yield of head rice: Per barrel, lbs.	Estimated yield of head rice: Per acre, lbs.	Estimated yield of head rice: Difference from average of variety, lbs.	Acre yield of straw, lbs.	Straw/grain ratio
"Indifferent," Group 2—*Concluded*												
Rexoro	1779	1932–37	Apr. 15	193	46	1,103[4]	59.6	42	286	+111	6,131	5.20
		1932–36	Apr. 29	180	43	860[4]	50.7	42	223	+ 48	5,609	6.88
		1932–37	May 16	[5]	41	252[4,6]	12.7	11	17	−158	8,489	30.43
		1932–37	May 30	[5]	[5]	[5]	0	[5]	—	—	[5]	[5]
		1932–37	June 16	[5]	[5]	[5]	0	[5]	—	—	[5]	[5]
Nira	2702	1935–39	Apr. 19	164	49	1,692	127.0	54	564	+127	3,649	2.11
		1935–36	May 1	159	44	1,413	96.0	55	480	+ 43	3,492	2.69
		1935–39	May 14	152	49	1,899	128.3	48	563	+126	9,068	3.78
		1935–39	May 30	149	45	1,368[4]	94.1	64	540	+103	7,729	5.74
		1935–39	June 18	[5]	36	198[7]	13.5	30	37	−400	[5]	[5]
Selection Edith × Fortuna (A. H.-28-24)	—	1937–39	Apr. 22	137	45	1,085	76.3	88	590	−134	—	—
		1937–39	May 13	128	43	1,314	100.0	87	706	− 18	—	—
		1937–39	May 31	125	39	1,584	119.3	85	831	+107	—	—
		1937–39	June 20	120	37	1,683	118.4	74	769	+ 45	—	—
Selection Improved Blue Rose × Fortuna (A. H.-29-39)	—	1937–39	Apr. 22	137	42	1,382	97.2	85	725	−129	—	—
		1937–39	May 13	128	40	1,674	127.4	86	888	+ 34	—	—
		1937–39	May 31	129	36	1,710	128.8	86	908	+ 54	—	—
		1937–39	June 20	121	38	1,908	134.2	76	895	+ 41	—	—

[1]Accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. Agriculture.
[4]Did not mature in 1937.
[5]Not fully mature before first killing frost.
[6]Produced some immature grain in 1932, 1934, and 1936.
[7]Produced some immature grain in 1939.

vesting and threshing and may also further deplete the soil fertility. However, if rice straw should become of importance in industry, data on its yield would be important.

The grain-straw ratio for Caloro was high for the first date of seeding, lower for the second, slightly reduced in the third, and then remained about constant.

The ratios for the early varieties, Colusa, Early Prolific, Zenith, and Storm Proof, were high for the first date of seeding, decreased for the next three dates of seeding, and increased again for the last date of seeding. The ratio for Supreme Blue Rose and Early Rose was low for the first date of seeding, slightly higher for the next three dates, and materially increased for the last date of seeding. The ratio for Fortuna, Rexoro, and Nira was somewhat different from that of the other seven varieties because of the poor grain development from the later dates of seeding. The ratio for Fortuna was comparatively low for the first three dates and higher for the last two dates of seeding. The ratio for Nira and Rexoro increased from the early to the late dates of seeding.

The relatively high yields of straw from the early dates of seeding were due to an increase in height and number of leaves on plants that continued in a vegetative stage over a long period. Bird damage to the grain of very early maturing varieties increased the proportion of straw in the total crop. Rice that matures late in the fall usually has a relatively high percentage of sterile florets and this, combined with a very leafy growth from June seeding, caused the grain-straw ratio for this date to be higher for most varieties than when sown earlier. The late-maturing varieties from the later dates of seeding probably were not fully mature when harvested and this increased the proportion of straw.

Most of the varieties produced more straw in proportion to grain when sown in April than when sown in May or June.

GRAIN YIELD

The grain yield is the most important record from a date of seeding experiment. The yields in pounds per acre are given in Table 1. The average yield of each variety for each date of seeding also is expressed as a percentage of the average yield of Supreme Blue Rose sown on the same date in the same years. Supreme Blue Rose was used as a standard because it is the most important commercial variety grown in Arkansas and produced the most uniform yields for all dates of seeding.

The values for the standard error of the mean, in percentage, were 4.67 for the April 15 seeding, 7.02 for the April 28 seeding, 3.95 for the May 15 seeding, 3.67 for the May 30 seeding, and 2.92 for the June 15 seeding. The values for the standard error of the difference, in percentage, were 13.20 for the first date, 19.86 for the second, 11.17 for the third, 10.38 for the fourth, and 8.26 for the fifth. The second date of seeding covered only five years which makes the standard error difference somewhat higher.

Caloro was grown only one year and the results, while not conclusive, indicate that the yield of this variety does not drop with

delayed seeding. The yields of Colusa were significantly lower for the first three dates of seeding than for the last two. The yields of Acadia were significantly higher for all dates of seeding than those of Supreme Blue Rose. The yields of Supreme Blue Rose were about the same for the first four dates of seeding but significantly lower for the fifth date. Early Prolific and Zenith gave very low yields for the first two dates of seeding but relatively high yields from May seedings with a slight reduction from June seeding. Early Rose gave comparatively low yields from all seedings which indicates why it has been dropped from commercial production. The selection Caloro × Blue Rose (A. H.-29-19) was grown three and the selection Kameji × Blue Rose (A. H.-29-128) only two years. The yields of these selections for the years grown indicate that they do not fluctuate greatly with seeding date. The yields of Arkansas Fortuna were high for the first four dates of seeding and the yield from the May 15 seeding was significantly higher than that for the other seedings. The yields of Storm Proof were low when sown in April but relatively high for the last three dates of seeding. The yields of this variety from May 29 seeding were significantly higher than for other seeding dates. The yields of Rexoro were very low from all dates of seeding. Nira produced high yields when sown in April and early in May but low yields from the late May and June seedings because the crop failed to mature in some years. The selection Edith × Fortuna (A. H.-28-24) gave very low average yields when sown in April and early May during the three years but gave significantly higher yields when sown in late May and June. The selection Improved Blue Rose × Fortuna (A. H.-29-39) gave a low average yield when sown in April and high yields when sown in May and June.

The varieties in group 1 produced relatively high yields of grain from all dates of seeding, although the highest yields were obtained from seeding in May. The highest yields of Arkansas Fortuna and Nira were obtained when sown in late April or early May. Zenith (group 2) gave the highest yields of rough and head rice when sown the latter part of May.

As pointed out by Nelson (10) seeding the middle of April was usually too early to obtain good stands owing to cool weather and competition with weeds and grass. In California, under different environmental conditions, Dunshee (4) and Jones (7) reported higher yields from sowing in April than on later dates. In Louisiana, Chambliss and Jenkins (3) reported that rice sown May 28 gave higher yields than when sown either earlier or later.

The results indicate that the varieties and selections Caloro, Acadia, Supreme Blue Rose, Caloro × Blue Rose (A. H.-29-19), and Kameji × Blue Rose (A. H.-29-128) may be sown to advantage over a longer period than the other varieties tested. However, these varieties should not be sown too early in April or much later than June 1. The highest yields of rough and head rice were obtained from seeding the last of April and during May.

A knowledge of the best variety to sow at any given period is important. The data indicate that the varieties best suited for sowing in April and early May are Acadia, Nira, Arkansas Fortuna, Selection

Caloro × Blue Rose (A. H.-29-19), and Supreme Blue Rose, and for for sowing in late May and June, Acadia, Zenith, Selection Caloro × Blue Rose (A. H.-29-19), and Early Prolific.

MILLING QUALITY

Rough rice (paddy) is the product as it comes from the thresher. It consists of the kernel (caryopsis) enclosed by the hulls (lemma and palea). Milled rice consists of the kernel with the hulls, bran, and embryo removed. The term "milling quality" usually refers to the amount of milled unbroken (head) rice obtained from a given quantity of rough rice and this largely determines the price of the latter. From the data presented (Table 1) it appears that milling quality is influenced to some extent by date of seeding. Certain varieties had a poorer milling quality when they were sown early and reached maturity before September 15 than when sown later and matured in late September or early October. This occurred in Colusa, Early Prolific, and Storm Proof varieties, and to a less extent in Zenith. Grain from the earlier dates of seeding of the midseason and late varieties was of good milling quality. The Arkansas Fortuna, Nira, and Rexoro varieties from the later dates of seeding were of very low milling quality because they did not fully mature before frost. The best milling quality for Arkansas Fortuna and Nira was obtained from seeding the latter part of April to May 15.

Many rice varieties produce grain that is "chalky" or opaque rather than translucent in appearance and of low milling quality when they ripen too early in the fall. The inferior quality appears to be due in part to high temperatures during the ripening period. The undesirable effect of high temperatures during the ripening period, however, has not been demonstrated under controlled conditions, but every year that the temperatures were abnormally high in August the rice that matured at that time was of low milling quality. Almost all varieties are affected to a greater or less extent. Therefore, to obtain high yields of good milling quality, early varieties should not be sown before the middle of May. Zenith proved to be the best early variety for seeding the middle of May. However, Early Prolific, Selections Edith × Fortuna (A. H.-28-24), and Improved Blue Rose × Fortuna (A. H.-29-39) also yielded well when sown May 15. The highest yields of head rice per acre for these four varieties and selections were obtained from seeding the last of May.

SUMMARY

The results of a date of seeding experiment with 15 varieties of rice are reported.

In response to date of seeding the varieties grown were grouped as (a) "sensitive" or (b) "indifferent." The "sensitive" varieties showed a gradual but marked decrease, ranging from 18 to 26%, in the number of days required to reach maturity when sown on successively later dates, and the "indifferent" varieties showed a small but less consistent shortening of the growth period, ranging from 9 to 15%, as sowing was delayed.

The "sensitive" varieties showed a gradual reduction in height from the first to the last date of seeding, whereas the "indifferent" varieties were variable, and, with certain exceptions, showed no consistent reduction in height due to delayed seeding.

Most varieties produced more straw in proportion to grain when sown in April than when sown in May or June.

The highest yields for the "sensitive" varieties and Zenith were obtained from seeding in May, and for the "indifferent" varieties, Arkansas Fortuna, and Nira, late in April or early May.

Most of the early and midseason varieties produced rice of better milling quality when they matured late in September or early in October than when they matured before September 15.

The data indicate that for best yields Supreme Blue Rose, Acadia, Caloro × Blue Rose, Kameji × Blue Rose, Arkansas Fortuna, and Nira should be sown before Zenith, Early Prolific, Colusa, Edith × Fortuna, and Improved Blue Rose × Fortuna. If sown in this order, the early varieties will mature before the late varieties. If this schedule were followed, none of the varieties would mature during the hot weather, but all would usually mature before bad weather begins and frost occurs in the fall.

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SPACING EXPERIMENTS WITH CORN[1]

A. A. Bryan, R. C. Eckhardt, and G. F. Sprague[2]

IN IOWA, corn is commonly check planted in hills spaced about 42 inches apart in rows of the same spacing. Planting rates vary from two to four plants per hill. Less frequently corn is drilled using the same row spacings. In general, drilled plantings produce slightly larger yields, but the differences are not great. Little work has been reported on row spacings closer than normal. Hume, Center, and Hegnauer[3] reported data in 1908 indicating a slight superiority of 33×33 inch over 44×44 inch spacing of hills in northern Illinois at both the two- and three-kernel planting rate. In central Illinois the same relation held for the two-kernel planting rate but was reversed when three kernels per hill were used.

In recent years there has been considerable interest in the possibility of increasing corn yields by planting in rows spaced only 21 inches apart. Some farmers who have tried this practice have reported obtaining considerable increases in yield. In preliminary trials the Agricultural Engineering Section, Iowa Agricultural Experiment Station, cooperating with the Bureau of Agricultural Chemistry and Engineering, U. S. Dept. of Agriculture, compared yields from two hill spacings, *viz.*, 21×21 inches, 1 plant per hill and 42×42 inches, 4 plants per hill. Larger yields were obtained from the 21-inch spacings.

The results presented here were obtained during a four-year period and include a number of different spacings with several hybrids.

MATERIAL AND METHODS

The experimental designs, strains, and spacings of the hills within the rows have varied somewhat from year to year. The row spacings of 21 and 42 inches have been used each season. Spacings within the rows have ranged from 42 to 10.5 inches and the number of plants per hill from one to four. All plots were completely bordered to reduce competition effects. Plantings in 1936 were made at double rates and the plants later thinned to the desired stands. In later years the plantings were made at the desired rate and no thinning was done. The detail of each experiment is presented with the data.

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, cooperating with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Agricultural Engineering Section, Iowa Agricultural Experiment Station cooperating with the Bureau of Agricultural Chemistry and Engineering, U. S. Dept. of Agriculture. Jour. paper J-781 of the Iowa Agricultural Experiment Station. Project No. 543. Received for publication June 26, 1940.

[2]Formerly Agronomist, Agent, and Agronomist, respectively, Division of Cereal Crops and Diseases; collaborators, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station.

[3]Hume, A. N., Center, O. D. and Hegnauer, Albert. Distance between hills of corn in the Illinois Corn Belt. Ill. Agr. Exp. Sta. Bul. 126. 1908.

EXPERIMENTAL RESULTS

1936 DATA

The 1936 tests included three hybrids (Iowa Hybrids 931, 939, and 13) and six spacings (42×42 inches, 21×29.4 inches, 21×24.5 inches, 21×21 inches, 21×18 375 inches, and 21×14.7 inches). The 42×42 inch spacing had four plants per hill, the remaining five spacings, in 21-inch rows, had single plants at the distances listed.

The experimental design was of the split-plot type. Each replication was divided into three blocks, each of which was subdivided into six sub-blocks. The three hybrids and the six spacings were assigned by lot to the blocks and sub-blocks, respectively. Twelve replications were used. The results are presented in Table 1.

TABLE 1.—*Acre yields in bushels of three hybrids grown at six different spacings in 1936.*

Space in inches between		No. of plants per acre (perfect stand)	Acre yields, bu.			Mean acre yields, bu.
Rows	Hills		Ia. 931	Ia. 939	Ia. 13	
42	42	14,224	30.2	39.2	51.0	40.3
21	29 4	10,160	33.6	48.5	55.8	46.0
21	24.5	12,192	33.1	41.3	54.9	43.1
21	21.0	14,224	28.4	40.8	55.6	41.6
21	18.375	16,256	27.7	37.5	52.8	39.3
21	14.7	20,320	23.8	35.2	52.4	37.1
Least significant difference, bu.			6.06			3.5

The growing season of 1936 was unusually hot and dry and yields ranged from 23.8 to 55.6 bushels per acre. Light showers in August and heavy September rainfall were of material benefit to the late Iowa Hybrid 13, and of much less benefit to the earlier Iowa Hybrids 939 and 931. The analysis of variance indicates that the difference in yields between hybrids and between spacings is significant. The variety × spacing interaction is not significant. The number of barren plants and the percentage of damaged kernels increased with increasing thickness of stand. In general, the highest yields were obtained from those spacings having fewest plants per acre. However, comparing the normal with the 21×21 inch spacing, which has the same number of plants per acre, the mean difference in yield over all hybrids, 1.3 bushels, is not significant.

1937 DATA

The 1937 tests were similar to those conducted in 1936 except that one new spacing, 42×10.5 inches, was added. Yield trends were reversed (Table 2), the spacings having the higher number of plants per acre producing the larger yields. The season of 1937 was very favorable for corn production. The analysis of variance indicates that variety and spacing differences and the variety × spacing interaction were all highly significant.

TABLE 2.—*Acre yields in bushels of three hybrids grown at seven different spacings in 1937.*

Space in inches between		No. of plants per acre (perfect stand)	Acre yields, bu.			Mean acre yields, bu.
Rows	Hills		Ia. 931	Ia. 939	Ia. 13	
42	42	14,224	90.4	101.5	106.2	99.4
42	10.5	14,224	84.6	96.9	100.8	94.7
21	29.4	10,160	83.2	91.9	91.0	88.7
21	24.5	12,192	86.7	98.0	98.5	94.4
21	21	14,224	91.2	104.0	102.3	99.2
21	18.375	16,256	90.6	107.3	107.7	101.9
21	14.7	20,320	92.2	105.4	115.7	104.4
Least significant difference, bu				2.83		1.63

The significant variety × spacing interaction appears to be related to the effect of spacing on tiller production. All three of the hybrids tiller freely under favorable conditions, but this tendency is most marked in Iowa Hybrid 13. In the closer spacings tillering was suppressed and larger yields resulted. However, the increases in yield differed in degree for the three hybrids.

Three of the seven spacings have the same number of plants per acre. Within this group no spacing produced a significantly higher yield than the standard 42×42 inch spacing. Among the other four spacings, which differ in the number of plants per acre, one cannot separate exactly the effect of plants per acre and different spacings.

1938 DATA

In 1938 eight strains were included in the test, four open-pollinated varieties and four hybrids The 21×24.5 inch spacing was discontinued and two new spacings were added, *viz.*, 42×31.5 inch and 42×21 inch. The design used was a two dimensional, quasi-factorial arrangement with two groups of sets and four replications. The yield data are presented in Table 3.

The year 1938 was favorable for corn production but less so than 1937, as indicated by the yields presented. A further indication of this is the fact that the spacings with more than 15,240 plants per acre produced the lowest yields. Of the spacings having 14,224 plants per acre, the 21×21 inch and 42×10.5 inch spacings produced significantly larger yields than the normal 42×42 inch spacing.

The analysis of variance for yields indicates that varietal and spacing differences were highly significant. The variety × spacing interaction was not significant. Strain differences for damaged kernels, moisture percentages, shelling percentage, and bushel test weight were significant, while spacing differences were not significant.

1939 TESTS

In 1939 one spacing (42×31.5 inch) was dropped, leaving seven different spacings. The four open-pollinated varieties and the early hybrid, Iowa Hybrid 931, were dropped and four new hybrids were added, making a total of seven hybrids. The experimental design used

was a 7×7 lattice square requiring four replications for balance. A total of eight replications were used, the second set of four replications being obtained by turning the first design through an angle of 90 degrees. The yield data are presented in Table 4.

The 1939 season was quite favorable, as evidenced by the large yields obtained. Among the four spacings having 14,224 plants per acre, the 21×21 inch spacing yielded significantly higher than the normal 42×42 inch spacing. There is a suggestion that slightly more plants per acre would have been preferable, as indicated by the large yield of the 21×18.375 inch spacing. The data also suggest that 20,320 plants per acre were too many.

The analysis of variance for yield indicates that strain and spacing differences were both highly significant. The seven hybrids did not behave similarly over all spacings, as indicated by a highly significant strain × spacing interaction.

In all four years some of the spacings used have varied from the standard, 42×42 inch, in number of plants per acre. When differences in yield were obtained, the difference in number of plants per acre complicates the interpretation. The relative amounts of the yield differences due to the differences in numbers of plants per acre and to the differences in row and hill spacings are not readily apparent from these experiments.

An attempt has been made to answer this question through an analysis of the covariance between yield and stand. In effect two stand corrections were made, the first for minor irregularities in stand within spacings and the second for the larger differences in stand among the different spacings. This second adjustment may be subject to some question, but since the average stand for all spacings differs from that used in the standard 42×42 inch spacing by only 580 plants per acre, it is believed that no serious bias is introduced.

When this method is applied to the 1939 data, the correlation coefficient for the error component is .208 and the regression of yield on stand .1059. Calculating the errors of estimate to provide a test of significance, we find that the mean square for error is reduced only slightly, from 6.59 to 6.33. The mean square for spacing differences is reduced considerably, from 32.87 to 20.68, indicating that a sizable portion of the spacing differences were related to stand differences. However, when the adjusted yields were calculated, it was found that mean yields were changed only slightly. The two spacings differing most widely from normal in number of plants per acre were changed the most by the adjustment process. As pointed out above, these changes may be questionable. However, neither before nor after adjustment are the yields of these spacings (10,160 and 20,320 plants per acre) significantly different from the standard. After adjusting yields on the basis of their regression on stand, the difference between the 42×42 inch and the 21×21 inch spacings is just significant, using odds of 20:1.

The average yields for the four-year period covering five different spacings is presented in Table 5. Two- and three-year averages for other agronomic characters also are presented in the same table. The yield comparisons of most interest involve the 42×42 inch and 21×21

TABLE 3.—*Acre yields in bushels of four open-pollinated varieties and four hybrids each grown at eight different spacings in 1938.*

Space in inches between: Rows	Space in inches between: Hills	No. of plants per acre (perfect stand)	No. of kernels per hill	Acre yields, bu.: Kossuth Reliance	Steen Y. D.	Black Y. D.	Krug	Ia. 931	Ia. 939	Ia. 13	Ia. 3110	Mean acre yields, bu.
42	42	14,224	4	68.5	68.3	74.0	70.2	61.5	79.9	77.0	91.7	73.9
42	31.5	15,240	3	62.4	74.0	77.7	69.0	63.8	87.9	89.4	98.1	77.8
42	21	14,224	2	65.4	71.0	77.5	61.3	65.5	73.0	77.9	93.1	73.2
42	10.5	14,224	1	61.5	63.3	63.7	58.8	74.6	87.3	98.6	101.1	76.1
21	29.4	10,160	1	72.0	64.7	80.1	72.1	63.9	76.5	88.4	102.4	77.5
21	21	14,224	1	66.3	74.8	63.2	67.9	69.9	91.9	87.5	97.4	77.4
21	18.375	16,256	1	54.8	54.9	64.3	59.5	60.8	70.0	71.6	87.7	65.5
21	14.7	20,320	1	59.9	60.1	57.6	57.0	63.3	66.1	71.9	96.6	66.6
Least significant difference, bu.				5.42								3.03

TABLE 4.—*Acre yields in bushels of seven double crosses grown in seven different spacings in 1939.*

Space in inches between: Rows	Space in inches between: Hills	No. of plants per acre (perfect stand)	No. of plants per hill	Acre yields, bu.: U. S. 13	U. S. 44	Ia. 939	Ia. 13	Ia. 3110	Ia. 3395	Ia. 3638	Mean acre yields, bu.: Observed	Adjusted
42	42	14,224	4	83.5	92.6	84.2	79.9	93.6	88.3	90.4	87.5	87.8
42	21	14,224	2	95.1	85.3	96.9	88.9	98.2	84.9	92.3	91.7	91.7
42	10.5	14,224	1	90.1	83.1	84.6	80.1	94.3	90.7	85.6	86.9	87.2
21	29.4	10,160	1	93.5	87.7	79.1	79.1	85.1	80.1	73.6	82.6	85.3
21	21	14,224	1	96.9	87.2	97.3	89.1	90.0	87.2	99.2	92.4	92.4
21	18.375	16,256	1	86.4	93.7	87.3	84.6	103.0	86.3	96.0	91.0	90.5
21	14.7	20,320	1	89.0	88.3	94.8	90.9	98.1	83.6	84.3	89.9	88.3
Least significant difference, bu.				11.4							4.1	

inch spacings. The difference in yield is 3.1 bushels, which is not significant, t equalling 1.85. The differences in moisture contents are not significant. Tillering exhibits a close relationship with number of plants per acre. The spacing having the fewest plants per acre (21×29.4 inch, with 10,160 plants) had the most tillers; the spacing with the largest number of plants per acre (21×14.7 inch, with 20,320 plants) had the fewest tillers. Other spacings were intermediate in tillering.

Planting rate also had a decided effect on the incidence of lodging. At the closest spacing, lodging was most severe, while the normal spacing had next to the least lodging recorded. The differences in lodging between the 42×42 inch spacing and the 21×21 inch or the closer spacings are significant at the 5% level. The effect of spacing on the number of ears per hundred plants or the number of ears per hundred-weight is what would logically be expected, with the largest number of plants per acre producing the smallest ears and the fewest ears per 100 plants. Test weight per bushel and shelling percentage do not differ significantly for different spacings.

DISCUSSION

The customary spacing of corn has been determined by trial and error on the part of farmers over a period of several decades. Before any change in planting practices is recommended any new spacing should exhibit a decided superiority to compensate for the cost of replacing planting, cultivating, and harvesting machinery. In the experiments reported here none of the spacings tried have been consistently superior to the normal 42×42 inch spacing in any important respect. The four-year average yield of the 21×21 inch spacing exceeded that of the 42×42 inch spacing by 3.1 bushels, which is a non-significant increase. Even if this difference were significant, it can hardly be considered a sufficiently large increase in yield to justify a change in common planting practices, especially as the normal spacing had a distinct advantage in lodging resistance.

The planting rate of 4 kernels per hill used here with the standard 42×42 inch spacing resulted in an expected stand of 14,224 plants per acre. This is a slightly heavier planting rate than is commonly used in Iowa. Robinson and Bryan[4] have shown that planting rates of this sort would result in increased yields over much of the state.

The experiments for the years 1937, 1938, and 1939 each included two or more hill spacings in 42-inch rows ranging from 42 to 10.5 inches apart. These and the 21×21 inch spacing all had the same expected number of plants per acre. None of these spacings has been consistently superior to the normal 42×42 inch spacing. This suggests that minor variations in hill spacing are not important when the number of plants per acre is constant.

SUMMARY

A number of corn hybrids and open-pollinated varieties were compared, using several different hill spacings. In two out of four years

[4]ROBINSON, J. L., and BRYAN, A. A. Iowa corn yield test. 1926.

TABLE 5.—*Average agronomic data recorded for five spacings for a two-, three-, or four-year period, 1936–1939, inclusive.*

Space in inches between		No. of plants per acre (perfect stand)	Acre yield, bu.*	Moisture content of grain, %†	Plants producing tillers, %‡	Lodging grade§	No. of ears per		Bushel test weight, lbs.†	Shelling percentage†
Rows	Hills						100 plants‡	Cwt.‡		
42	42	14,224	77.3	16.1	4.3	1.3	95.3	211.6	57.0	84.3
21	21	14,224	80.4	15.7	9.5	1.5	96.2	197.8	56.9	84.1
21	29.4	10,160	76.3	16.4	25.8	1.1	108 9	167.4	57.1	83.7
21	18.375	16,256	75.5	16.4	5.2	1.8	90.6	216.0	57.0	84.1
21	14.7	20,320	75.5	16.2	2.4	2.1	84.5	265.7	56.7	84.2

*Four-year period, 1936–39.
†Three-year average, 1937–39.
‡Two-year period, 1937–38.
§Two-year period, 1938–39; the lower grades indicate less lodging.

the 21×21 inch spacing exceeded the 42×42 inch spacing by a significant amount. The difference between four-year averages for these two spacings, however, is not significant. The closer spacings consistently had more lodged plants than the wider spacings.

In general, it appears that no consistent and material advantage will result from spacings closer than now normally used. Within the comparisons involving the same number of plants per acre minor variations in spacing had little effect on acre yield.

GERMINATION OF FRESHLY HARVESTED SEEDS OF SEVERAL *POA* SPECIES AND OF *DACTYLIS GLOMERATA*[1]

V. G. SPRAGUE[2]

THE freshly harvested seeds and fruits of many plants are characterized by a dormant period during which germination is greatly retarded or completely inhibited. Changes may take place after a storage period of several weeks or months which allow the seed to germinate normally. Flemion (3, 4),[3] Gassner (5), Harrington (6), Haut (8), Kearns and Toole (9, 10), Smith (12), and Toole (13) have shown that germination was increased by chilling the moistened dormant seed of several widely different species for varying lengths of time. Fivaz (2), Gassner (5), Harrington (7), Morinaga (11), and others have shown that non-dormant seeds often germinate better under daily alternation of temperatures than under constant temperatures.

In a cytogenetic or breeding study of any plant it is usually desirable to obtain successive generations as frequently as possible. This may necessitate germinating the seed as soon as it has been produced. In the cytogenetic program at the U. S. Regional Pasture Research Laboratory difficulty was encountered in obtaining adequate germination of freshly harvested seeds[4] of *Poa pratensis* L. several other *Poa* species, and *Dactylis glomerata L.* To develop simple technics which would induce prompt germination of the freshly harvested seed of these species, the following experiments were conducted.

EFFECT ON GERMINATION OF TIME AND TEMPERATURE OF STORAGE OF DRY SEED OF *POA PRATENSIS*

The open-pollinated seed used in these experiments was harvested on June 21, 1938, from six plants growing in the field nursery. Seed from three of the plants contained 12 to 13% moisture at the time of harvesting, while seed from the other three contained 24 to 33%. After the seed had air dried for two weeks the moisture content of all lots was between 10 and 11%. Germination tests in this and all subsequent experiments were conducted with samples of 50 seeds each placed in Petri dishes on blotters moistened with 0.1% potassium nitrate solution. The seeds were selected individually with tweezers to make certain that each was plump and well formed.

One sample from each of the six lots was placed on a moist blotter for germination at room temperature (22° to 26° C). The pretreat-

[1]A contribution from the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Received for publication July 2, 1940.

[2]Associate Agronomist.

[3]Numbers in parenthesis refer to "Literature Cited", p. 721.

[4]In this paper, "seed" is defined in the broad sense as the caryopsis plus adhering glumes.

ments consisted of storing dry samples from each of the six lots at temperatures of 43°, 22° to 26°, 0°, and -7° C for periods of 4, 8, 16, 32, and 64 days. At the end of each storage period the seeds were moistened with 0.1% potassium nitrate solution and placed at room temperature where they received north light. The percentage germination was recorded every three days for a four-week period and all germinated seeds were removed when counted.

Since no significant differences were shown in the germination of the six lots of seed which originally had differed in moisture content, the results from all of the seed lots were averaged (Table 1). It is evident that storage of the dry seed for any of the periods shorter than 64 days did not increase the percentage germination. The seed stored at 43° C for this latter period showed an increased germination (52%) when compared to the germination (22 to 33%) of those lots stored at the other temperatures. At the end of the four-week germination period the seed from all treatments was placed in a cold chamber at 7° C for 12 days and then returned to room temperature for three additional weeks. This uniform cold treatment increased germination to about 90%.

TABLE 1.—*Average germination of six lots of freshly harvested seed of Poa pratensis subjected to different temperatures for varying lengths of time.*

Pretreatment temperatures, °C	Pretreatment time, days													
	0		4		8		16		32		64		Average	
	A*	B†	A	B	A	B	A	B	A	B	A	B	A	B
43°	—	—	1	92	1	88	2	92	1	82	52	90	11.4	88 8
0°	—	—	0	84	1	91	1	91	1	89	22	88	6.2	88.6
-7°	—	—	0	91	2	91	1	90	2	90	30	91	7.0	90.6
22° to 26°	1	79	—	—	—	—	—	—	—	—	33	90	—	—
Average			0.3	89	1.3	90	1.3	91	1.3	87	35.7	89.7	8.2	89.3

*Average percentage germination of six seed lots at the end of four weeks at 22° to 26°.

†Average percentage germination of the same six seed lots at the end of three additional weeks at 22° to 26° after the seed had been treated at 7° C for 12 days following the previous germination period of four weeks at room temperature

EFFECT OF STORAGE TEMPERATURE ON MOISTENED SEED OF *POA PRATENSIS*

Additional seed was harvested from the same six plants on July 6, 1938. The moisture content of this seed ranged from 10 to 11%. The seed had been stored at room temperature for four weeks when the germination tests were begun. One dish from each lot was allowed to germinate at room temperature. Four additional samples from each lot of seed were placed on the moistened blotters and allowed to remain at room temperature for 24 hours. One dish from each lot was then placed at a temperature of 43° C, 7° C, 0° C, and -5° C for seven days, after which they were returned to room temperature. The percentage germination was recorded every three days for two weeks, at which time germination had almost stopped. At this time all lots

of seed were transferred to a temperature of +7° C where they were allowed to remain 11 days before being again returned to room temperature. Germination percentages were recorded at three-day intervals for two weeks.

The six lots of seed used in each treatment were averaged (Table 2). It is evident that the dormancy of the moistened seed was not broken by seven days at room temperature (22° to 26° C), at 43° C, or at −5° C, but that at 0° C the dormancy was partially broken and that at 7° C the seed germinated very well. Following the second storage treatment at 7° C for 11 days, all samples had germinated over 90%, except those which had previously been subjected to −5° C. It appears that this temperature may have been low enough to injure the viability of some of the seed.

TABLE 2.—*Average germination of six lots of freshly harvested seed of Poa pratensis.*

Pretreatment of moist seed	Germination at 22° to 26° C two weeks after treatment, %	Total germination at 22° to 26° C two weeks after chilling ungerminated seed at 7° C for 11 days, %
None	0	94
7 days at 43° C	0	93
7 days at 7° C	75	92
7 days at 0° C	39	96
7 days at −5° C	0	83

GERMINATION OF *POA PRATENSIS* SEED SIX MONTHS AFTER HARVESTING

Part of the seed harvested July 8, 1938, was stored at room temperature for six months. Samples of 50 seeds each were used to study the effects of various temperature and light conditions on germination. The conditions used and the percentage germination obtained with each are presented in Table 3. After six months the seed had apparently lost its dormancy since germination of 90% or over was obtained without cold treatment. Satisfactory germination was obtained at 15° C and at 10° C constant temperatures and at daily alternations of temperatures of 15° C to 30° C and 10° C to 30° C. A constant temperature of 5° C appears to be too low for rapid germination, as is evidenced by a germination of only 60% after four weeks. However, transferring these lots to room temperature for one week increased germination to 90%. Very little effect of light on the germination was observed in these studies. While the percentage germination was slightly lower in the lots receiving alternating 20° and 30° C in darkness than those receiving 20° C in darkness and 30° C for 6 hours in north light, those lots at 15° C and 10° C which were in continuous darkness (except for the time when the dishes were removed for counting) germinated as well as those under north light.

TABLE 3.—*Average germination of six lots of Poa pratensis seed after storage for six months at room temperature.*

Germinating conditions*	Germination end of two weeks, %	Germination end of four weeks, %
20°–30° C	93	94
20°–30° C dark	90	91
Room temperature (22° to 26° C)	89	90
15°–30° C	91	94
15° C, dark, 10 days; then 20°–30° C	87	94
15° C dark	90	94
10°–30° C	76	87
10° C, dark, 10 days; then 20°–30° C	88	93
10° C dark	84	94
5°–30° C	29	88
5° C dark, 10 days; then 20°–30° C	0	90
5° C dark	0	60†

*The lower temperature was maintained in darkness and the higher temperature in north light, except where otherwise stated.
†One week at 22° to 26° C increased germination to 90%.

COMPARATIVE EFFECT OF CONSTANT LOW TEMPERATURES AND ALTERNATING TEMPERATURES IN INCREASING GERMINATION IN FRESHLY HARVESTED SEED OF *POA PRATENSIS*

On March 15, 1939, seed was harvested from several clones of *Poa pratensis* growing in the greenhouse. The seed was threshed, composited, and allowed to air-dry for one week before being sampled and placed on moistened blotters. All samples of seed were allowed to remain at room temperature for 24 hours to absorb moisture before they were subjected to the following temperature treatments: (a) 20° to 30° C; (b) 20° to 30° C (in darkness at both temperatures); (c) room temperature; (d) 15° to 30° C; (e) 15° for 10 days, then 20° to 30° C; (f) 10° to 30° C; (g) 10° for 10 days, then 20° to 30° C; (h) 5° to 30° C; (i) 5° C for 10 days, then 20° to 30° C. The low temperature interval was 18 hours in the dark and the high temperature interval was 6 hours in north light except in b.

Triplicate samples in each treatment were used and the number of germinated seeds recorded every three days. The results of these treatments are summarized in Table 4. It is evident from these data that at alternating temperatures of 15° to 30° C and 10° to 30° C much better germination was obtained than at 20° to 30° C or 5° to 30° C. They further indicate that alternating temperatures are much more effective than low temperatures for a continuous period of 10 days, except at the lowest temperature of 5° C, where the relationship appears to be reversed. Light during the 30° C period seemed to have little effect in aiding germination as is evident in comparing the 20° to 30° C series in light and continuous darkness.

GERMINATION OF FRESHLY HARVESTED SEED OF FOUR *POA* SPP.

A small quantity of open-pollinated seed was available in March 1939 from greenhouse plants of each of the following species: *Poa*

TABLE 4.—*Germination of freshly harvested seed of Poa pratensis composited from greenhouse plants.*

Germinating conditions*	Total germination at†		
	2 weeks %	4 weeks %	6 weeks %
20°–30° C	0	3	5
20°–30° C dark	1	9	11
Room temperature (22° to 26° C)	0	0	1
15°–30° C	11	47	77
15° C, dark, 10 days; then 20°–30° C	5	9	10
10°–30° C	14	87	91
10° C, dark, 10 days; then 20°–30° C	7	9	13
5°–30° C	0	4	5
5° C dark, 10 days; then 20°–30° C	0	28	29

*The lower temperature was maintained in darkness and the higher temperature in north light, except where otherwise noted.
†Each figure is the average of three replicates.

compressa L, *P. palustris* L, *P. alpina* L, and *P. arachnifera* Torr. One 50-seed sample of each species was subjected to an alternating temperature of 20° C for 18 hours in the dark and 30° C for 6 hours in north light, the germinating conditions recommended (1) in general for forage grasses. A second set of samples was given a 10-day cold treatment at 10° C in the dark before being subjected to the 20° to 30° C alternating temperatures (Table 5). With these species the percentage germination was increased by a temperature of 10° C for 10 days followed by alternating temperatures of 20° to 30° C. *Poa*

TABLE 5.—*Germination of freshly harvested seed of several Poa species from greenhouse plants, open-pollinated seed of several plants within each species composited.*

Species	Germinating conditions*	Germination at end of				
		1 week %	2 weeks %	3 weeks %	4 weeks %	6 weeks %
Poa compressa	20°–30° C	14	42	68	68	84
Poa compressa	10° C dark, 10 days; then 20°–30° C	6	66	80	84	84
Poa palustris	20°–30° C	26	54	84	84	86
Poa palustris	10° C dark, 10 days; then 20°–30° C	6	82	98	100	100
Poa alpina	20°–30° C	0	0	0	0	0
Poa alpina	10° C dark, 10 days; then 20°–30° C	66	98	98	98	98
Poa arachnifera	20°–30° C	0	0	0	0	0
Poa arachnifera	10° C dark, 10 days; then 20°–30° C	0	2	22	24	24

*The lower temperature was maintained in darkness and the higher in north light, except where otherwise noted.

alpina was perhaps most striking in its response to the lower temperture. Within 10 days it had germinated 94% at 10° C, whereas at the alternating temperature of 20° to 30° C it showed no evidence of germination, even after five weeks. The germination of all species increased at the lower temperatures, with the exception of *P. compressa*, which showed no improvement at the end of five weeks.

EFFECT OF TEMPERATURE ON GERMINATION OF FRESHLY HARVESTED SEED OF *DACTYLIS GLOMERATA*

During the summer of 1939 difficulty was experienced in obtaining good germination of freshly harvested seed of *Dactylis glomerata*. Open-pollinated seed from three clones in the field was placed under germinating conditions similar to those used with success on *Poa pratensis*. Samples of 50 seeds each were placed on moistened blotters and given the following treatments: (a) One sample of each clone at daily alternating temperatures of 22° to 28° C; one sample of each clone at each of the constant temperatures of (b) 15° C, (c) 10° C, and (d) 5° C for 14 days in darkness and then returned to 22° to 28° C conditions; and one sample of each clone at each of the daily alternating temperatures of (e) 15° to 28° C, (f) 10° to 28° C, and (g) 5° to 28° C. Inasmuch as no differential response of the three clones to germinating conditions was apparent, the results from the clones have been averaged (Table 6).

TABLE 6.—*Average germination of freshly harvested field seed of Dactylis glomerata.*

Germinating conditions*	Germination after two weeks, %†	Germination after four weeks, %†
22°–28° C	23	26
14 days at 15° C, then 22°–28° C	91	91
14 days at 10° C, then 22°–28° C	90	92
14 days at 5° C, then 22°–28° C	0	93
15°–28° C	96	96
10°–28° C	95	97
5°–28° C	39	95
Average	62	84

*The lower temperature was maintained in darkness and the higher in north light.
†Each figure is the average of duplicate samples of three clones germinated separately.

The germination of freshly harvested seed of *Dactylis glomerata* was increased when the moistened seed was subjected to a temperature of 10° to 15° C for a 14-day period and then removed to 22° to 28° C temperatures, or when the moistened seed was alternated daily between the low temperatures and 28° C. The alternation of low and high temperatures resulted in a slightly higher germination percentage than did constant low temperatures for a 14-day period followed by a temperature of 22° to 28° C.

SUMMARY

1. Freshly harvested seed of *Poa pratensis* and *Dactylis glomerata* were dormant when subjected to the recommended (1) germinating temperatures of 20° to 30° C.

2. By subjecting moistened dormant field seed of *Poa pratensis* and *Dactylis glomerata* to temperatures between 5° and 15° C for a period of 10 to 14 days over 90% germination was obtained.

3. With greenhouse seed alternating temperatures of 10° to 30° C or 15° to 30° C increased germination more effectively than constant temperatures of 10° and 15° C.

4. Seed of *Poa pratensis* was not dormant six months after harvest. At this time the effects of light and various temperatures on germination were not marked.

5. Freshly harvested seed of *Poa compressa*, *P. palustris*, *P. alpina*, and *P. arachnifera* from greenhouse plants showed various degrees of dormancy in germination at alternating temperatures of 20° to 30 °C. Chilling the moistened seed at 10° C for 10 days before subjecting them to the higher alternating temperatures increased germination.

6. For germinating freshly harvested seed of the species studied the best treatment consisted of daily alternating temperatures of 10° to 30° C or 15° to 30° C with the lower temperature effective for 16 to 18 hours and the higher temperatures for 6 to 8 hours. Where daily alternation is impractical, as with large quantities of field-grown seed, storage of the moistened seed at 10° to 15° C for two weeks with subsequent removal to room temperature may produce acceptable germination.

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MANGANESE, COPPER, AND MAGNESIUM CONTENTS OF SOME COMMERCIAL FERTILIZERS[1]

C. E. MILLAR AND W. S. GILLAM[2]

THE need of supplying one or more of the nutrients, nitrogen, phosphoric acid, and potash to most soils to increase crop production has been recognized for over a century. The fertilizer industry has been developed on the basis of the insufficient supply of these nutrients in an available form in agricultural soils. In recent years, research in plant nutrition has directed attention to the requirement of plants for small quantities of other elements, as copper, manganese, and magnesium. Studies of the soil supply and the role in plant growth of the so-called minor elements have evoked considerable interest, as is evidenced by the voluminous literature on the subject. Since, in some localities, and under certain conditions, it has been found advisable to recommend the application of small quantities of some of these elements as a part of the fertilization practice, it seemed of interest to have some knowledge concerning the amounts of these elements present in commercial fertilizers in common use.

The present investigation was undertaken with this point in mind and sets forth the results obtained from analysis of 11 commercial fertilizers (2–12–6) for manganese, copper, and magnesium.

EXPERIMENTAL

The samples of commercial fertilizers used in this investigation were furnished by the state chemist, Mr. Wm. Geagley, and were portions of samples taken according to standard methods for use in persuance of his chemical control duties in the administration of the fertilizer licensing law.

TREATMENT OF SAMPLES

The equivalent of a 10-gram sample of the oven-dry fertilizer was placed in a casserole and 20 cc of 18 N sulfuric acid added. The mixture was then heated until the material was well charred. The solution was allowed to cool, 16 N nitric acid was added until violent reaction ceased, and the solution was again heated until the fertilizer was thoroughly charred. Again it was cooled, 16 N nitric acid added as before and the solution heated until thick fumes of sulfuric acid were evolved. This procedure was repeated until the solution became clear and remained so when strongly heated. The solution was then evaporated just to dryness, 200 cc of 6 N sulfuric acid added, and the solution boiled. The hot solution was then filtered, the residue was thoroughly washed with hot dilute sulfuric acid, and the filtrate and washings were made to volume and reserved for analysis.

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[1]Contribution from the Soils Section of the Michigan Agricultural Experiment Station, East Lansing, Mich. Authorized by the Director for publication as Journal Article No. 459 (n.s.). Received for publication August 1, 1940.

[2]Professor and Assistant Professor of Soils, respectively.

To a fairly large aliquot of this solution 10 drops of thymol blue indicator were added (6).[a] While vigorously stirring the solution, ammonium hydroxide was added dropwise until the color changed from pink to yellow. The pH of this solution was approximately 2.8 and it was buffered by the addition of 25 cc of a 25% solution of ammonium acetate. At this stage a slight flocculent precipitate usually formed. The solution was then heated to 70° to 80° C, maintained at this temperature for 30 minutes, and allowed to stand until the precipitate settled. Finally, the solution was filtered and the precipitate was washed with hot 5% ammonium nitrate. The precipitate, consisting of iron and aluminum phosphates, was discarded. The filtrate and washings were combined, made to volume, and reserved for final analysis.

Calcium was removed from the above solution by double precipitation of the oxalate, after the method of Kolthoff and Sandell (4). The filtrates and washings from these precipitations were collected, evaporated to dryness, ignited, taken up in water, and made to volume. This solution was then analyzed for manganese, copper, and magnesium.

DETERMINATION OF MANGANESE

An aliquot of 50 cc of the test solution was placed in an Erlenmeyer flask along with 0.2 to 0.4 gram of solid potassium periodate and 10 to 15 cc of concentrated nitric acid (9). One cc of syrupy phosphoric acid was added and the solution was boiled for a few minutes and then cooled. The red to pink color began to develop on heating and reached its maximum on cooling. The solution was then transferred to a 100-cc volumetric flask and diluted to the mark. Finally, it was placed in an optical cell and read in a Fisher photometer.

The calibration curve for the instrument was obtained, with the aid of a Wratten green light filter No. 58, by treating standard solutions of manganese sulfate, as described above, and reading in the photometer. An excellent curve was obtained which readily permitted evaluation of concentrations of manganese ranging from 0.2 to 10 p.p.m.

DETERMINATION OF COPPER

A 50-cc aliquot of the test solution was transferred to a 250-cc separatory funnel and 1 cc of concentrated hydrochloric acid and 10 cc added of a solution containing 150 grams of citric acid per liter. Concentrated ammonium hydroxide was then added to the solution, dropwise, until just alkaline to litmus. Ten cc of 0.1% solution of sodium diethyl-dithiocarbamate (1) were then added and the total volume made up to 100 cc. The colored compound formed upon addition of the carbamate reagent was then extracted with carbon tetrachloride in three separate portions. These extractions were made by using two 5-cc and one 10-cc portions of carbon tetrachloride, accurately measured. After vigorously shaking each mixture and allowing the layers to separate the colored carbon tetrachloride solution

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[a]Figures in parenthesis refer to "Literature Cited", p. 725.

was drawn off into a dry test tube, the three portions being collected in the same container. The combined fractions, totaling 20 cc, were then placed in a small optical cell and read in the photometer.

The concentration of copper was then determined from the calibration curve prepared from standard solutions with the aid of a Wratten blue light C-5 filter No. 47. The curve covered a range of 10 to 160 p.p.m. of copper.

DETERMINATION OF MAGNESIUM

Since aluminum, iron, and phosphorus were present in varying amounts, care was taken to insure their removal before magnesium was determined. Iron phosphate, aluminum phosphate, calcium phosphate, and magnesium phosphate have a minimum solubility (8) at pH 2.2, 3.7, 6.5, and 10, respectively, but when the solution contains a mixture of these constituents iron and aluminum phosphates precipitate out (6) at pH 2, and magnesium phosphate remains in solution until a pH greater than 7 is reached. For this reason, as previously pointed out, a portion of the original acid extract was carefully brought to pH 2.8. This insured precipitation of most of the iron, aluminum, and phosphorus, while magnesium remained in solution. If the phosphorus content of the solution is high, it can be removed by the addition of small quantities of iron, such as ferrous ammonium sulfate.

A small aliquot of the solution was placed in a 100-cc volumetric flask and the concentration of magnesium was determined colorimetrically by a method previously described (3).

Results of the analyses are presented in Table 1, while in Table 2 are summarized findings relative to the amounts of manganese, copper, and magnesium occurring in certain farm products.

TABLE 1.—*Manganese, copper, and magnesium contents of some commercial 2-12-6 fertilizers.*

Fertilizer No.	Mn expressed as pounds of anhydrous $MnSO_4$ per ton of oven-dry fertilizer	Cu expressed as pounds of $CuSO_4.5H_2O$ per ton of oven-dry fertilizer	Mg expressed as pounds of $MgSO_4.7H_2O$ per ton of oven-dry fertilizer
16339	0.014	0.0004	1.57
16341	0.004	0.0004	0.42
16345	0.012	0.00000014	4.56
16348	0.004	0.0000003	0.70
16353	0.016	0.0000003	0.47
16380	0.018	0.0004	17.73
16383	0.012	0.00000034	2.88
16416	Trace	0.00000064	6.02
16440	0.009	0.00000012	0.91
16444	0.010	0.00000056	0.45
16446	0.009	0.0000003	2.03

CONCLUSIONS

The data in Table 1 show that all samples of fertilizer contained determinable quantities of copper and magnesium and, with one

TABLE 2.—*Minor elements contained in certain farm products.*

Crop	Amount	Lbs. of Mn as $MnSO_4$*	Lbs. of Cu as $CuSo_4.5H_2O$†	Lbs. of Mg as $MgSO_4.7H_2O$‡
Corn........	40 bu.	0.034	0.044	14.78
Oats	40 bu.	0.13	0.034	9.41
Wheat	25 bu.	0.13	0.046	12.10
Rye..	20 bu.	——	0.026	8.19
Barley	30 bu.	0.055	0.041	10.57
Soybeans	20 bu.	0.11	0.107	102.65

*Data from Schaible, *et al.* (7).
†Data from Elvehjem (2).
‡Data from Millar (5).

exception, of manganese. The quantities of the elements present in the samples studied were extremely variable and in no instance large. Magnesium occurred in larger quantities than either of the other two elements and manganese ranked second.

Compared to the quantities of these elements contained in normal yields of several commonly grown crops (Table 2) the amounts found in the fertilizers are quite small with the exception of the magnesium content of sample No. 16380.

As the usual application of fertilizer is a small fraction of a ton per acre it appears that the crop must depend very largely on the soil for the required amounts of the elements under consideration.

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NOTE

THE DISTRIBUTION OF CANADA BLUEGRASS AND KENTUCKY BLUEGRASS AS RELATED TO SOME ECOLOGICAL FACTORS[1]

MUCH controversy exists as to the factors which determine the distribution of Canada bluegrass, *Poa compressa* L., and Kentucky bluegrass, *Poa pratensis* L. The general consensus of opinion prevails that Kentucky bluegrass is best adapted to rich land soils, while Canada bluegrass may be found to dominate under a wider range of conditions. The investigation of Hartwig[2] concerning the incidence of these two Poas indicates that differences in chemical composition of the soil beneath the two species do occur.

In the vicinity of the Ohio Experiment Station, Canada bluegrass has been frequently observed growing on roadway cuts where the clay subsoil has been exposed by road construction. In many instances Kentucky bluegrass was found in an adjacent area on the surface soil above. In rare cases it was observed to be established on the roadway cut adjacent to Canada bluegrass. Observations of the soils under the two sod types suggested that Kentucky bluegrass inhabited the darker and more friable soil. In the analysis of paired soil samples from roadway cuts, the average percentage organic matter was 2.1 under Kentucky bluegrass as compared to 1.3 under Canada bluegrass, as shown in Table 1. This same trend was shown in percentage total nitrogen of the soils. The range in pH of the soils was from 6.0 to 7.3, little difference being obtained between the paired samples.

Pure stands of the two species growing adjacent to each other in pastures were difficult to locate. Unpaired soil samples collected in 1938 from sods, both pastured and unpastured, gave the same trends in organic matter as those of paired samples. The data are presented in Table 2. The pH values were in general higher under Kentucky bluegrass sods than under Canada bluegrass. Moisture equivalent determinations on these same soils gave no definite differences. Field moisture determinations made at definite intervals during the summer of 1937 on a few soils were higher in soils under Kentucky bluegrass than under Canada bluegrass. The great amount of variation existing in these unpaired samples places a question on the validity of the results under these conditions.

A number of observations were made in the course of the study which are of interest. Frequently Canada bluegrass was found growing in dense stands under maple trees along the highway. Away from the trees, Kentucky bluegrass dominated. It is not known whether this resulted from shading, soil moisture, or some other factor or a group of factors.

On first examination of roadway cuts, the position or direction of slope where sods were growing appeared to be a factor involved. Upon

[1]Joint contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and the Agronomy Department, Ohio Agricultural Station, Wooster, Ohio.

[2]HARTWIG, H. B. Relationships between some soil measurements and the incidence of the two common Poas. Jour. Amer. Soc. Agron., 10:847–861. 1938.

TABLE 1.—*Analyses of soil samples from roadway cuts, 1939.*

	Kentucky bluegrass			Canada bluegrass		
Soil No.	pH	N, %	Organic matter, %	pH	N, %	Organic matter, %
1	6.5	0.08	1.5	6.7	0.07	1.1
2	6.9	0.07	1.5	6.8	0.05	0.7
3	6.9	0.08	3.1	6.9	0.05	0.9
4	6.9	0.09	1.6	7.0	0.06	0.9
5	7.2	0.07	1.0	7.2	0.06	0.6
6	7.0	0.08	1.5	7.2	0.04	0.2
7	7.1	0.10	1.7	6.6	0.07	1.1
8	6.6	0.13	2.1	6.7	0.10	1.7
9	6.2	0.11	1.9	6.1	0.13	2.6
10	6.8	0.09	3.0	6.8	0.08	1.1
11	6.0	0.13	3.2	6.0	0.08	1.2
12	6.6	0.10	1.7	6.6	0.13	2.3
13	6.2	0.19	3.4	6.6	0.11	1.8
14	7.1	0.15	4.8	7.0	0.08	1.3
15	6.8	0.12	2.1	6.9	0.08	1.1
16	7.3	0.17	3.1	7.3	0.10	2.1
17	7.2	0.09	1.7	7.2	0.07	1.2
18	6.9	0.07	1.1	7.1	0.03	0.3
19	7.2	0.06	1.1	7.3	0.10	1.9
20	7.1	0.08	1.3	7.3	0.08	1.5
Av.....		0.10	2.1		0.08	1.3

more detailed observation, both species were found growing on all types of slope regardless of direction or steepness. The factors responsible for the establishment of Kentucky bluegrass on the cuts are not definitely known. It was never found growing on new cuts or

TABLE 2.—*Analysis of soil samples from pastured and unpastured areas, 1938.*

	Kentucky bluegrass			Canada bluegrass			
Soil No.	pH	Organic matter, %	Moisture equivalent, %	Soil No.	pH	Organic matter, %	Moisture equivalent, %
1	6.8	5.7	12.1	51	5.9	4.0	18.6
2	6.7	5.1	12.5	52	5.7	2.7	20.6
3	6.9	7.4	25.2	53	5.9	2.8	22.2
4	6.5	4.6	23.8	54	6.3	3.9	21.6
5	6.8	3.8	25.8	55	6.1	3.2	27.8
6	6.2	4.2	25.8	56	6.7	4.8	23.0
7	6.1	7.0	18.3	57	7.0	3.8	25.1
8	6.4	8.1	30.6	58	6.2	4.7	13.0
9	6.8	6.2	25.0	59	6.9	3.2	20.5
10	7.1	3.6	24.5	60	5.7	4.3	24.3
11	6.3	6.4	28.6	61	5.6	2.0	15.9
12	6.1	5.5	13.1	62	5.6	2.7	20.1
13	6.3	6.5	21.6				
14	6.4	3.0	17.1				
15	6.5	5.0	23.6				
Av.....		5.5	21.8	Av.....		3.5	21.0

on stony clay soil such as that where Canada bluegrass was frequently found dominating.

In an effort to elucidate the problem of differences in fertility of soils dominated by the two species, yields of plant parts were determined on six square-foot areas from broadcast plots of each species in the summer of 1939. Average yields of plant parts of Kentucky bluegrass were slightly higher than those of Canada bluegrass when compared on a dry weight basis In the study it was observed that rhizomes of Kentucky bluegrass penetrated to a greater depth than those of Canada bluegrass.

The foregoing results and observations did not appear sufficient to warrant a complete publication. Since it was not feasible to continue with a thorough investigation, it seemed desirable to offer such information as was obtained, with the idea, that it might initiate further investigation.—JAMES M. WATKINS, *formerly of the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture;* G. W. CONREY, *Ohio Experiment Station;* and MORGAN W. EVANS, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Wooster, Ohio.*

BOOK REVIEWS

A STUDENT'S BOOK ON SOILS AND MANURES

By E. J. Russell. New York: The Macmillan Company. Ed. 3. VIII + 296 pages, illus. 1940. $2.50.

THE first edition of this book was published in 1915 and was twice revised. In the present volume the text is again completely revised and very largely re-written making available new material along many lines. It is written at a time when the British national need for increased food production is especially urgent, so has as its aim the instruction of students and farmers in methods of securing the greatest returns from the soil through cultivation and manuring.

The first part of the book deals with matters of more fundamental nature such as plant and soil composition and their interrelations, organic matter, and the effect of climate on soil conservation. Part 2 deals with cultivation and the control of soil fertility, while part 3 has to do with mineral fertilizers, organic manures, lime, and methods of fertilizing various crops. A short appendix presents some data of field experiments, handy tables, and composition of a few crops.

The text is well arranged, interestingly written, and although primarily prepared for British agriculture, contains, like all the author's works, a great deal of value for the American student and farmer. (R.C.C.)

FRENCH-ENGLISH SCIENCE DICTIONARY

By Louis De Vries. New York: McGraw-Hill Book Co., Inc. VIII + 546 pages. 1940. $3.50.

COMPILED by the author, who is Professor of Modern Languages at Iowa State College, with the collaboration of members of the Graduate Faculty at Ames, this dictionary was planned and

started several years ago to assist candidates for advanced degrees in acquiring a reading knowledge of the French language. It corresponds in many respects to the recently published German-English Science Dictionary from the same source.

No claim to completeness is made for the dictionary, but it contains 43,000 entries, including terms of the agricultural, biological, and physical sciences, as well as many literary terms. Special attention has been given to the French irregular verb and its many forms. Also, some 500 common idioms have been included.

The book is well printed, bound in flexible covers, and is of a size to make a convenient reference work for the student's desk. (J.D.L.)

AGRONOMIC AFFAIRS

THE SOIL SCIENCE SOCIETY PROCEEDINGS

VOLUME 4 of the Soil Science Society PROCEEDINGS containing the papers presented at the New Orleans meeting in November, 1939, is now available. The volume contains 455 pages, is printed by letterpress, and is cloth bound. The price is $5.00, post paid, and orders should be sent directly to Dr. G. G. Pohlman, Treasurer of the Soil Science Society, Agricultural Experiment Station, Morgantown, W. Va.

TOBACCO FERTILIZERS

RECOMMENDATIONS for fertilizers for flue-cured tobacco grown on average soils in Virginia, North and South Carolina, Georgia, and Florida have been prepared by an Agronomy Tobacco Work Conference of representatives of these states and of the U. S. Dept. of Agriculture. Professor C. B. Williams of the North Carolina Experiment Station was Chairman of the Conference and Professor T. B. Hutcheson of the Virginia Experiment Station, Secretary.

The recommendations deal with analyses of mixtures and rates of application, neutral fertilizers, and fertilizers for plant beds. Mimeographed copies of the recommendations may be obtained upon application to Professor Hutcheson at Blacksburg, Va.

FILM STRIP FOR 1941

ANNOUNCEMENT has been made by the Extension Service of the U. S. Dept. of Agriculture that the contract for film-strip production for the fiscal year of 1940–41 has again been awarded to Photo Lab, Inc., Washington, D. C., and that the prices will be the same as those in effect the past year.

Included in the subjects dealt with in these film strips are soil conservation, farm crops, farm forestry, and plant diseases and pests. Further information on film strips and how to purchase them may be had by writing to the Extension Service in Washington.

NEWS ITEMS

PROFESSOR R. M. SALTER, Associate Director of the Ohio Agricultural Experiment Station, has been appointed as Director of the North Carolina Agricultural Experiment Station. He succeeds Dean I. O. Schaub who has been Acting Director since Dr. R. Y. Winters resigned several years ago to accept a position in the Office of Experiment Stations.

DOCTOR L. D. BAVER, Professor of Agronomy in charge of Soils, at the Ohio State University, will accompany Professor Salter as Head of the Department of Agronomy and Associate Director of the Agricultural Experiment Station. He succeeds Professor C. B. Williams who was retired July 1. The administration prevailed on Dr. G. K. Middleton to serve as Acting Head of Agronomy during the short interval between the retirement of Professor Williams and the completion of arrangements with Dr. Baver. Professor Salter and Dr. Baver will assume their new duties October 1.

DOCTOR N. D. MORGAN, horticulturist at the North Louisiana Agricultural Experiment Station, has resigned to join the field staff of the American Potash Institute, with headquarters at Shreveport, La. In his new position he will carry on the educational program of the Institute in the Southwestern states, cooperating with state and college agricultural forces, the fertilizer trade, and growers, on problems of soil management involving the efficient use of fertilizer.

L. M. THOMPSON who for the past year has been Junior Soil Surveyor with the Soil Conservation Service in Texas returned to his position as Instructor of Agronomy with the Department of Agronomy of the Agricultural and Mechanical College of Texas on September 1, from which he had a year's leave.

H. E. HAMPTON, Instructor in the Department of Agronomy, Agricultural and Mechanical College of Texas, College Station, Texas, was granted a year's leave of absence to enter the University of Missouri where he began work toward his doctor's degree during the summer of 1940.

DOCTOR B. D. WILSON, research professor of soil technology at Cornell University and long an active member of the Society, died on September 5 as a result of injuries sustained in an automobile accident at Warren, Ohio, while returning to Ithaca, N. Y., following a visit to his home in Kentucky.

IN THE August number of the JOURNAL it was incorrectly stated that Charles A. Rowles of the University of Saskatchewan was granted the Ph.D. degree in Agronomy and Plant Genetics at the University of Minnesota last June. Actually, he received the degree in Soils at the University of Minnesota.

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FACTORS INFLUENCING THE GERMINATION OF SEED OF *TRIFOLIUM REPENS*[1]

GLENN W. BURTON[2]

WHITE clover (*Trifolium repens* L.) when grown in the Southeast usually behaves as a winter annual. In early summer, after producing seed, most of the plants die and the seeds remain dormant until fall or early winter. The seeds then germinate, the seedling plants make their main growth in early spring, produce seeds, and die, thus completing their life cycle.

It has been observed that white clover seed planted early in the fall becomes established quicker and can be pastured earlier than white clover which has reseeded naturally. In average seasons white clover is a valuable source of winter pasturage in Florida and south Georgia, and since the earlier it becomes established the earlier it can be grazed, some men are making light seedings of commercial seed early in the fall instead of waiting for volunteer seedings to produce a stand. Since in unusually dry or very cold seasons these early seedings fail to survive or produce little if any winter pasturage, the practice of making early seedings involves certain risks which many men will not care to take. These observations indicate that a strain of white clover producing seed 20 to 30% of which will germinate early in the fall from natural reseedings may prove valuable in this area.

MATERIAL AND METHODS

In an effort to determine whether or not such strains might be present in the white clover breeding material at Tifton, Ga., seed was harvested from 93 plants, the strain-building progeny of 17 selections, in the first week in June, 1939. These seeds were stored at room temperature until August 9, 1939, when scarified (scarified uniformly with sandpaper) and unscarified seeds of these plants were germinated at 10°, 20°, and 30° C, approximate mean winter, fall, and summer air temperatures, respectively, at Tifton, Ga.

One hundred seeds of each treatment were germinated in miniature "rag-doll" testers made of paper towelling labelled with India ink. The germination tests on

[1]Cooperative Investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, Tifton, Ga., and the Georgia Experiment Station, Experiment, Ga. Received for publication June 17, 1940.

[2]Geneticist, U. S. Dept. of Agriculture, Tifton, Ga.

unscarified seed were run in duplicate. All samples germinating at any one temperature were placed together at random in a specially constructed moist chamber. Germinated seeds were counted and removed on August 16, 23, and 31 and on September 6. Due to the large volume of this germination data only a summary showing the general effect of scarification and temperature upon the seed of these 93 strains has been presented in Table 1.

RESULTS AND DISCUSSION

Table 1 shows that at the end of 28 days the freshly harvested unscarified seed germinated 3.1, 3.6, and 64.3% at 30°, 20°, and 10° C. That a change favoring germination occurred within the seed only at 10° is worthy of note. Samples of the same seed when scarified germinated 70.7, 89.9, and 95.3%, respectively, at the above temperatures. While most of the samples varied little from these mean values, unscarified seed of one selection germinated 4.5% at 30° and 14.5% at 20°.

The fact that scarified seed germinated an average of 70.7% at 30° C. indicates that the principal factor inhibiting the germination of unscarified seed at 20° and 30° was removed by scarification. Since the germination of scarified seed at 30° was significantly lower than at 20° and 10°, it would seem that 30° was too high for the most satisfactory germination.

TABLE 1.—*The average germination of scarified and unscarified seed of 93 selections of Trifolium repens held in germinators at 10°, 20°, and 30° C.**

Length of germination period, days	Percentage of unscarified seed germinated at			Percentage of scarified seed germinated at			Least significant difference	
	30° C	20° C	10° C	30° C	20° C	10° C	1% point	5% point
7	0.7	2.7	21.9	44.7	87.7	87.0	5.2	4.0
14	1.7	3 1	44.5	63.6	88.4	92.1	5.8	4.4
21	2.4	3.4	58.1	68.8	89.3	93.4	6.1	4.6
28	3.1	3.6	64.3	70.7	89.9	95.3	5.7	4.3

*This study was begun two months after the seed was harvested.

GERMINATION FOLLOWING COLD STORAGE

In an effort to explain why the differences presented above were obtained, seed of four strains of white clover which had responded differently in the first test were studied in some detail 7 months after harvest. During the 5-month period between these two studies the seeds were stored in a room with the relative humidity ranging from 60 to 100% and temperatures ranging from 5° to 15° C. Fitting this study to a factorial design, duplicate samples of scarified and unscarified seed of each strain were germinated at 10°, 20°, and 30° C in the same manner as in the previous study. To determine the effect of the temperature and scarification treatments on the rate of water absorption each 100 seed sample was weighed before and 5, 29, and 47 hours after it was placed in the germinators.

The weight increase data and the mean squares of the analysis of variance of it are presented in Tables 2 and 3. Table 3 shows that at the end of 5 hours seed treatment and temperature were the only significant sources of variation. The data revealed that scarified seed absorbed 9.2 times more water than unscarified seed in the initial 5-hour period. Water absorption at 10° and 20° was essentially the same, but at 30° the seeds absorbed 35% more water than at the two lower levels.

TABLE 2.—*The influence of temperature and scarification upon the relative increase in weight of seed harvested from four selections of white clover in 1939 and stored for five months in a room with the relative humidity near 100% and temperatures ranging from 5° to 15° C.*

Strain No.	Average percentage weight increase of all samples germinated at the temperatures indicated						Average percentage weight increase of all samples receiving the treatment indicated			
	No. of observations	10° C	20° C	30° C	Mean: No. of observations	Mean: All temperatures	No. of observations	Seed scarified	Seed not scarified	Difference*
Percentage Weight Increase 5 Hours After Seed Was Placed In Germinators										
2-34	4	23.3	26.6	28.8	12	26.2	6	46.1	6.4	39.7
2-56	4	24.4	24.4	32.2	12	27.0	6	51.0	3.1	47.9
3-108	4	23.9	20.0	38.4	12	27.5	6	49.9	5.0	44.9
7-75	4	22.4	23.6	27.5	12	24.5	6	43.0	6.1	36.9
Mean	16	23.5	23.7	31.8	48	26.3	24	47.5	5.1	42.4
Percentage Weight Increase 29 Hours After Seed Was Placed In Germinators										
2-34	4	56.4	76.8	98.5	12	77.2	6	88.6	65.8	22.8
2-56	4	59.8	64.1	84.7	12	69.6	6	86.2	53.0	33.2
3-108	4	61.0	78.2	93.7	12	77.6	6	91.4	63.9	27.5
7-75	4	42.7	50.3	58.6	12	50.6	6	79.0	22.1	56.9
Mean	16	54.9	67.3	83.9	48	68.7	24	86.3	51.2	35.1
Percentage Weight Increase 47 Hours After Seed Was Placed In Germinators										
2-34	4	69.4	102.3	164.1	12	111.9	6	127.4	96.4	31.0
2-56	4	77.6	84.8	110.4	12	90.9	6	108.2	73.7	34.5
3-108	4	85.6	103.9	130.6	12	106.7	6	123.4	90.0	33.4
7-75	4	60.8	76.1	92.1	12	76.3	6	120.5	32.1	88.4
Mean	16	73.3	91.8	124.3	48	96.5	24	119.9	73.1	46.8

*The least significant mean difference at the 5% point between means of 4, 6, 12, 16, and 24 observations for weight increase after 5 hours is 9.8, 8.0, 5.6, 4.9, and 4.0%; for weight increase after 29 hours is 10.3, 8.4, 5.9, 5.1, and 4.2%; for weight increase after 47 hours is 24 7, 20.2, 14.2, 12.3, and 10.0%, respectively.

After 29 hours it is evident from Table 3 that strains, temperature, and seed treatment varied significantly in weight increase. At 10°, 20°, and 30° the total relative weight increase for the four strains was 100.0, 122.7, and 152.8%, respectively.

Although at the end of 5 hours the scarified seed had a weight increase which was 9.2 times greater than that of the unscarified seed,

after 29 hours it was only 69% greater than the unscarified seed. Since the weight increase for the 24-hour period was only 82% of the increase for the first 5-hour period, it is apparent that the rate of water absorption decreased rapidly as the scarified seeds approached saturation.

TABLE 3.—*Analysis of variance on a study of the increase in weight of scarified and unscarified seed of four Trifolium repens strains held in germinators at 10°, 20°, and 30° C.*

Source of variation	DF	Mean square of increase in weight of seed after		
		5 hours	29 hours	47 hours
Total	47	—	—	—
Strains	3	20.0	1930.4†	3070.0†
Temperature	2	355.7†	3371.3†	10627.9†
Treatment	1	21505.4†	14805.1†	26296.9†
Temperature × treatment	2	107.2	278.1†	505.7
Strains × temperature	6	54.1	145.5*	963.3†
Strains × treatment	3	74.0	685.6†	2315.9†
Strains × temperature × treatment	6	45.9	31.8	165.0
Error	24	45.0	49.8	287.5

*Significant.
†Highly significant.

The increase in rate of water absorption associated with a temperature increase caused the scarified seed to absorb increasingly greater quantities of water than unscarified seed at higher temperature levels. This accounts for the significant temperature × treatment interaction.

The nature of the strains × temperature interaction can be illustrated by the fact that at 20° and 30° selection 3-108 had total weight increases over that at 10° which were 60.5 and 90.5% greater than the corresponding weight increases for 7–75. Thus temperature increased the rate of water absorption in 3-108 more than in 7–75. This difference in rate of water absorption between 3–108 and 7–75 is probably due to the fact that 7–75 possessed a much larger percentage of "hard seeds" which had a very low rate of water absorption.

The highly significant strains × treatment interaction is easily understood in light of the fact that scarification at the end of 29 hours increased the water absorption in 3–108 and 7–75, 43.2 and 357.3%, respectively. Thus the percentage of hard seeds made permeable by scarification was much higher in 7–75 than in 3–108.

Since the temperature × treatment interaction was not significant after 47 hours, it is evident that the favorable influence of the higher temperature on the rate of water absorption was overcome as the seeds became saturated with water. All other relationships were essentially the same as described for the 29-hour period.

The percentage germination after 3, 7, 14, and 21 days was determined for each sample in this study. The data for the first three germination counts and the mean squares of the variance for the various sources of variation are presented in Tables 4 and 5.

It is interesting that after 3 days all sources of variation except the triple interaction were highly significant. Considering first strains and the interactions involving them, the data showed that the total germination for all samples of 3–108 was 63.7% greater than that of 7–75. For the first 3 days temperature increase had a greater effect upon the germination of 7–75 than on 3–108. This was probably due to the fact that 3–108, having a faster rate of water absorption, reached its requirements for germination so much earlier than 7–75 that the favorable influence of temperature on rate of water absorption was no longer expressed to the same degree in the germination response of 3–108 as it was in 7–75.

Since scarification increased the germination of the seed of 3–108 by 20.5% and increased the germination of 7–75 by 228.0%, the nature of the significant strains × treatment interaction is quite apparent.

TABLE 4.—*The influence of temperature and scarification upon the germination of seed harvested from four selections of white clover in 1939 and stored for five months in a room with the relative humidity near 100% and temperatures ranging from 5° to 15° C.*

Strain No.	Average percentage germination of all samples germinated at the temperatures indicated						Average percentage germination of all samples receiving the treatment indicated			
	No. of observations	10° C	20° C	30° C	Mean: No. of observations	Mean: All temperatures	No. of observations	Seed scarified	Seed not scarified	Difference*
Percentage Germination 3 Days After Seed Was Placed In Germinators										
2–34	4	13.5	65.0	76.0	12	51.5	6	59.2	43.8	15.4
2–56	4	24.5	60.0	66.8	12	50.4	6	55.3	45.5	9.8
3–108	4	15.2	72.8	73.0	12	53.7	6	58.7	48.7	10.0
7–75	4	6.8	41.5	48.0	12	32.1	6	49.2	15.0	34.2
Mean	16	15.0	59.8	65.9	48	46.9	24	55.6	38.2	17.4
Percentage Germination 7 Days After Seed Was Placed In Germinators										
2–34	4	68.7	68.0	78.0	12	71.6	6	80.7	62.5	18.2
2–56	4	71.0	67.8	71.2	12	70.0	6	79.9	60.2	19.7
3–108	4	84.0	82.7	79.2	12	82.0	6	86.0	78.0	8.0
7–75	4	47.5	48.0	53.2	12	49.6	6	72.9	26.3	46.6
Mean	16	67.8	66.6	70.4	48	68.3	24	79.9	56.8	23.1
Percentage Germination 14 Days After Seed Was Placed In Germinators										
2–34	4	70.0	69.2	78.0	12	72.4	6	82.2	62.7	19.5
2–56	4	75.5	68.8	74.2	12	72.8	6	83.8	61.8	22.0
3–108	4	85.5	84.8	81.5	12	83.9	6	88.5	79.3	9.2
7–75	4	49.5	49.8	53.5	12	50.9	6	74.7	27.2	47.5
Mean	16	70.1	68.1	71.8	48	70.0	24	82.3	57.7	24.6

*The least significant mean difference at the 5% point between means of 4, 6, 12, 16, and 24 germination counts after 3 days is 9.7, 7.9, 5.6, 4.8, and 4.0%; after 7 days is 7.8, 6.3, 4.5, 3.9 and 3.2%; after 14 days is 7.0, 5.7, 4.0, 3.5, 2.8%, respectively.

TABLE 5.—*Analysis of variance on a study of the germination of scarified and unscarified seed of four Trifolium repens strains held in germinators at 10°, 20°, and 30° C.*

Source of variation	DF	Mean square for germination of seed after		
		3 days	7 days	14 days
Total	47	—	—	—
Strains	3	1195.3*	2206.7*	2286.8*
Temperature	2	12374.0*	60.9	54.5
Treatment	1	3605.0*	6394.1*	7227.5*
Temperature × treatment	2	562.7*	159.6*	202.6*
Strains × temperature	6	178.3*	47.7	46.4
Strains × treatment	3	397.5*	811.7*	795.4*
Strains × temperature × treatment	6	98.1	29.7	33.2
Error	24	44.3	28.5	22.9

*Highly significant.

The fact that temperature and the strains × temperature interaction were not significant at the end of 7 days indicates that the principal effect of higher temperatures was to increase the rate of water absorption and growth, and that at the end of one week the total requirements had been reached at all temperature levels.

Comparing the total germination of all scarified and unscarified samples scarification increased the germination the first 3 days 45.3%.

The close relationships between water absorption as measured by weight increase of the seeds and germination indicates that the germination of white clover seed is dependent largely upon its ability to absorb water. The highly significant correlation coefficients of +.52, +.55, and —.73 obtained between the germination in 3 days and the weight increase of seed after 5, 29, and 47 hours lends weight to this conclusion. The fact that a fair percentage of commercial white clover seed is scarified and hence will absorb water readily probably explains why early fall seedings of commercial seed will germinate and become established earlier than natural reseedings.

The data showing the germination performance of selections 7–75 and 3–108, 2 and 7 months after the seeds were harvested is presented in Table 6. These data show in detail the previously discussed effects of temperature and treatment upon the germination of these two lots of seed. The new feature of particular interest presented here lies in the comparison of the germination response of strains 7–75 and 3–108, 2 and 7 months after harvest. It is quite apparent from the data presented in Table 6 that 5 months' storage in a room with a relative humidity from 60 to 100% and temperatures ranging from 5° to 15° C brought about changes in the seed which caused the unscarified seed to germinate much better at 20° and 30° than it had 5 months earlier.

In the case of 3–108 this change was so great that unscarified seed germinated about as well as scarified seed. Since scarified seed of 7–75 germinated much better than unscarified seed even after 5 months' storage, it is evident that this change in 7–75 was much less pronounced than in 3–108.

TABLE 6.—*The influence of scarification, temperature, and storage upon the germination of seed harvested from two selections of white clover in 1939.**

Germination temperature °C	Seed treatment†	Two months after harvest, germination percentage after				Seven months after harvest, germination percentage after			
		7 days	14 days	21 days	28 days	3 days	7 days	14 days	21 days
		Selection 7-75							
10	U	19.5	43.5	61.0	69.5	3.5	28.5	30.0	33.0
10	S	70.0	82.0	90.0	90.0	10.0	66.5	69.0	71.5
20	U	7.0	8.5	8.5	8.5	14.0	18.5	19.0	19.0
20	S	30.0	31.0	33.0	34.0	69.0	77.5	80.5	81.5
30	U	0.0	2.0	4.0	4.0	27.5	32.0	32.5	32.5
30	S	37.0	45.0	52.0	53.0	68.5	74.5	74.5	75.0
		Selection 3-108							
10	U	53.5	86.5	92.5	97.0	13.5	83.5	85.0	85.5
10	S	97.0	99.0	100.0	100.0	17.0	84.5	86.0	87.0
20	U	0.5	0.5	0.5	0.5	67.0	78.0	78.0	78.0
20	S	98.0	98.0	99 0	100.0	78.5	87.5	91.5	92.0
30	U	1.0	2.0	2.0	3.0	65.5	72.5	74.5	74.5
30	S	68.0	71.0	74.0	76.0	80.5	86.0	88.0	88.0

*After the first test the seed were stored in a room, with the relative humidity near 100% and temperatures ranging from 5° to 15° C.
†U = Unscarified; S = Scarified.

In an effort to explain why after 3 days unscarified seed of selection 2-56 germinated 68.0%, while unscarified seed of 7-75 germinated only 22.5%, a difference which existed throughout the test, the following comparisons were made of the seeds of these two selections: The weights of 12 100-seed samples of each selection revealed that the seeds of 2-56 with an average weight of 55.0 mgm per 100 seeds were significantly heavier than the seeds of 7-75 which averaged 41.2 mgm per 100 seeds.

Microscopic measurements of cross sections of the seed coat on 65 seeds of these two selections indicated that they did not differ significantly in seed coat thickness.

Using La Motte's Duplex indicator for soils, the pH of crushed light yellow seeds of these two selections was determined. The seed coats of both selections stained a deep red of the same intensity showing a pH of 4.0 or below. The cotyledons on both strains stained a yellowish orange indicating a pH of about 5.5.

Since 7-75 seemed to contain a higher percentage of red seeds than 2-56, red and yellow seeds were separated from the seed of 7-75 and were studied for rate of water absorption and germination. Although red seeds germinated slightly better than yellow ones, the difference was not significant.

Of these comparative measurements 7-75 and 2-56 differed significantly only in the weight of 100 seeds. Assuming the same density in both seed lots, the smaller seeds would have the greater surface or the greater seed coat area per unit of material contained

within. If the seed coats of large and small seeds were equally permeable, the small seeds should become saturated before the large ones. Since the seeds of 7–75 were smaller and were also slower in absorbing water and germinating than those of 2–56, it is evident that the seed coats of 7–75 were much more impermeable to water than the seed coats of 2–56. Whether this difference in permeability is due to the kind of fatty materials in the seed coat, the manner in which they are distributed or some other unrelated factors awaits the proof of intensive micro-chemical studies.

SUMMARY

1. Two months after harvest, unscarified seed of 93 selections of white clover, held in germinators at 30°, 20°, and 10° C for 28 days, germinated an average of 3.1, 3.6, and 64.3%, respectively. The same seed when scarified germinated 70.7, 89.9, and 95.3% at these temperatures. Thus it is apparent that the principal factor inhibiting germination of clover seed at 20° and 30° was removed by scarification. The average germination of the unscarified seeds suggests that some type of internal change comparable in effect to scarification of the seed coat occurs only at 10° C.

2. Five months storage at 5° to 15° C and at high relative humidities increased appreciably the germination at 20° and 30° C of unscarified seed of four of the selections that were tested.

3. Significant strain differences in response to cold storage, scarification, and temperature increase were noted.

4. Temperature increase hastened water absorption and germination but had little effect upon total germination.

5. Seed scarification increased the rate of water absorption, the rate of germination, and total germination in all four strains tested. The favorable effect of scarification was most pronounced when seeds were germinated at high temperature levels.

6. The highly significant correlation coefficients of +.52, +.55, and +.73 obtained between germination in 3 days and weight increase of seed after 5, 29, and 47 hours indicates that the germination of white clover seed is associated with its ability to absorb water.

7. Selections 7–75 and 2–56 which responded very differently to cold storage did not differ significantly in seed coat thickness, in pH of seed coat and cotyledon, or in percentage germination of red and yellow seeds. Seeds of 7–75, which were least affected by cold storage, were significantly smaller than the seeds of 2–56.

EFFECTS OF ROTATIONAL AND MANURIAL TREATMENTS FOR TWENTY YEARS ON THE ORGANIC MATTER, NITROGEN, AND PHOSPHORUS CONTENTS OF CLARION AND WEBSTER SOILS[1]

W. J. PEEVY, F. B. SMITH, AND P. E. BROWN[2]

IT HAS been observed quite generally that yields decline on soils soon after they are first brought under cultivation, especially where continuous cropping has been practiced. The decreased productivity has been ascribed to a depletion of the readily available plant food constituents, the changes in physical and biological conditions of the soil attendant upon cultivation, and the loss in organic matter. Numerous experiments under widely differing conditions as to soils, climate, and cropping systems have been conducted. Some of these experiments have been carried on over extended periods and much information has been obtained. White (11)[3] reported that on similarly treated soils there exists a close ratio between total yields of crops and the residual soil organic matter.

Salter and Green (6) presented data showing the changes in nitrogen and organic carbon in Wooster silt loam under continuous cropping and various rotations. It was estimated that a single year's cropping to the various crops increased or decreased the organic carbon content of the soil by the following percentages of the total amount present in the soil: Corn, -3.12; wheat, -1.44; oats, -1.41; hay in a 5-year rotation (timothy predominating), +1.36; and hay in a 3-year rotation (clover), +3.25. The corresponding values for nitrogen were: Corn, -2.97; wheat, -1.56; oats, -1.45; hay in a 5-year rotation, +0.64; and hay in a 3-year rotation, +2.87.

Blair and Prince (2) reported analyses of soils collected from cylinders and from field plats which had been cultivated and cropped for periods of 25 to 35 years and of soils collected in the beginning of the experiment. It was shown that continuous cropping even with fertilizer additions tended toward a depletion of the organic matter and nitrogen contents of the soil. There was an increase in the amount of phosphorus in the cultivated and fertilized soil and in one case the percentage of phosphoric acid was more than doubled in a period of 25 years.

Karraker (4) determined the gains and losses of nitrogen in variously treated plats during a 7-year period. He reported a loss of 530 pounds of nitrogen per acre in a soil kept bare, a gain of 62 pounds per acre under bluegrass, and a gain of 405 pounds in a soil under bluegrass and white clover.

Metzger (5) in a study of nitrogen and organic carbon of soils as affected by crops and cropping systems found that corn was more destructive of nitrogen and carbon than any other crop studied. Alfalfa and cowpeas added to the supply of soil nitrogen, but cowpeas were more destructive of soil carbon than alfalfa. Manure failed to produce significant increases in nitrogen or carbon above that which could be attributed to increased crop residues.

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[3]Figures in parenthesis refer to "Literature Cited", p. 752.

The effect of continuous cropping to corn for 19 years on the contents of organic matter, nitrogen, and phosphorus and on the pH of Clarion loam has been reported (8). It was found that considerable losses in organic matter, nitrogen, and phosphorus occurred even when relatively large applications of manure were made.

The purpose of the present study was to determine the effect of various soil treatments and of different crop rotations on the changes in the organic matter, nitrogen, and phosphorus contents of soils during a period of 20 years.

GENERAL PLAN OF EXPERIMENT

The 2-year, 3-year, and 5-year rotation plats which had been established at the Agronomy Farm near Ames in 1914 were selected for this study (9).

In these experiments every crop in the rotation has been planted each year. That is, replicate blocks with all treatments are planted to each crop each year. For example, the plats of the 2-year rotation are arranged in two blocks, the one planted to corn and the other to oats. Each block is divided into four 1/10-acre plats 28 feet in width and two 1/20-acre plats 14 feet in width. The plats are separated by 7-foot borders The soil treatments made in each block of the 2-year rotation were as follows: (a) Check; (b) manure and lime; (c) manure, lime, and rock phosphate; (d) crop residues and lime; (e) crop residues, lime, and rock phosphate; (f) check. In this rotation the manure was added in 1914 and every other year thereafter at the rate of 4 tons per acre. The lime was added as ground limestone in 1914 and thereafter when necessary to neutralize the acidity of the soil. Rock phosphate was applied at the rate of 500 pounds per acre once in the rotation.

The plats under the 3-year rotation of corn, oats, and clover are arranged in three blocks, each containing six plats similar in size and shape to those in the 2-year rotation. The treatments made in each block were the same as those made in the 2-year rotation. The manure was applied at the rate of 6 tons per acre once in the rotation. Ground limestone was added as necessary to neutralize the acidity of the soil and the rock phosphate was applied at the rate of 750 pounds per acre once every 3 years.

The plats of the 5-year rotation, probably better designated as a modified 4-year rotation, are arranged in five blocks. Each block contains 11 1/10-acre plats 28 feet wide and 155.6 feet long and are separated by 7-foot borders. For 20 years a 4-year rotation of corn, oats, clover, and wheat is used, and for the next 5 years the plats are planted with alfalfa. The treatments made on the 11-plat blocks were as follows: (a) Check; (b) manure; (c) manure and lime; (d) manure, lime, and rock phosphate; (e) manure, lime, and superphosphate; (f) check; (g) crop residues; (h) crop residues and lime; (i) crop residues, lime, and rock phosphate; (j) crop residues, lime, and superphosphate; (k) check. The manure was applied at the rate of 8 tons per acre once every 4 years, except before the alfalfa seeding when it was applied at the rate of 10 tons per acre. Limestone was added to neutralize the acidity of the soil. The rock phosphate was applied at the rate of 1,000 pounds per acre once every 4 years, except before the seeding of alfalfa when 1,250 pounds per acre were applied. The superphosphate (20% P_2O_5) was applied at the rate of 120 pounds per acre to each grain crop in the rotation, except before the seeding of alfalfa when the rate was 300 pounds per acre.

The layout of the continuous corn plats and the plats of the 2-, 3-, and 5-year rotations is given in Fig. 1. The Roman numerals and letters in the figure refer to the block number.

The plats of the 2-, 3-, and 5-year rotations were sampled both in 1917 and in 1937. The 1917 samples consisted of five borings, one taken at each corner and one at the center of each plat. For the purpose of sampling in 1937 each plat was divided lengthwise into three sections, each approximately one-third the width of the plat. Three borings approximately 50 feet apart were taken from each section, starting at random from 5 to 35 feet from one end of the plat. The borings from each section were composited, giving three composite samples from each plat. The soils were air-dried, mixed thoroughly, and ground for analysis. The organic matter, nitrogen, and phosphorus contents were determined in duplicate on each sample. The results were calculated on a moisture-free basis.

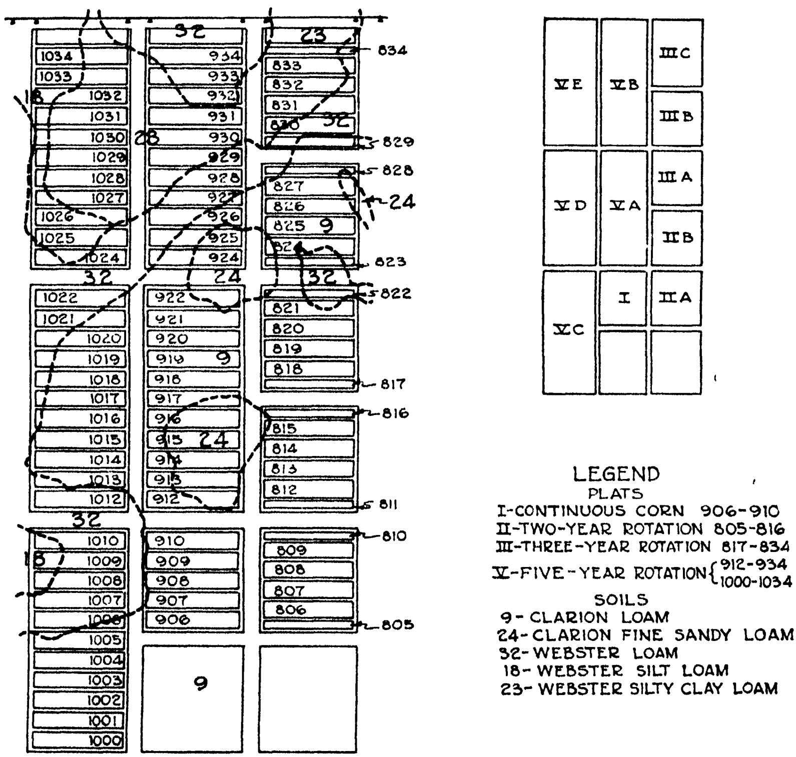

FIG. 1.—Rotation experiments, Agronomy Farms, Iowa State College, Ames, Iowa.

Nitrogen was determined by the Gunning-Hibbard method (1). The inorganic carbon was determined by the Schollenberger (7) method, and the total carbon by the dry combustion method. The organic carbon was obtained by subtracting the values for inorganic carbon from the value for total carbon. The factor 1.724 was used to convert organic carbon to total organic matter. Total phosphorus was determined by the modified magnesium nitrate method (3).

RESULTS

ORGANIC MATTER CHANGES

The data on the organic matter content of the samples taken from the plats in the 2-, 3-, and 5-year rotations are presented in Tables 1, 3, and 4. The tests of significance of the gains or losses during the 20-year period from 1917 through 1937 are also shown in Table 2.

As shown in Table 1, four out of the five plats in the 2-year rotation which did not receive manure lost highly significant amounts of organic matter, whereas only one of the three plats which received manure showed a significant loss. The average loss of organic matter where no manure had been applied was 16.2%.

All the no-treatment plats in the 3-year rotation showed significant losses of organic matter, the average loss amounting to 11.7%; whereas, only one out of seven plats receiving the various treatments showed a significant loss (Table 3).

TABLE 1.—*Changes in contents of organic matter, nitrogen, and phosphorus from 1917 to 1937 in soil of variously treated plats under corn-oats rotation.*

Treatment	Plot No.	Year sampled	Organic matter, %		Nitrogen, %		Phosphorus, %	
			Block II-A	Block II-B	Block II-A	Block II-B	Block II-A	Block II-B
None	805; 810 811; 816	1917 1937	4.26 3.74	3.94 3.14	0.19 0.16	0.18 0.13	0.040 0.038	0.037 0.036
Difference			−0.52†	−0.80†	−0.03†	−0.05†	−0.002	−0.001
Manure and Limestone	806 812	1917 1937	——‡ 3.62	3.84 3.22	——‡ 0.16	0.17 0.14	——‡ 0.039	0.038 0.040
Difference				−0.62†		−0.03†		0.002
Manure, limestone, and rock phosphate	807 813	1917 1937	3.86 3.61	3.33 3.03	0.18 0.17	0.16 0.14	0.042 0.062	0.039 0.051
Difference			−0.25	−0.30	−0.01	−0.02	0.020†	0.012†
Crop residue and limestone	808 814	1917 1937	——‡ 3.89	3.15 2.71	——‡ 0.18	0.15 0.13	——‡ 0.042	0.033 0.036
Difference				−0.44		−0.02		0.003
Crop residue, limestone, and rock phosphate	809 815	1917 1937	4.74 4.01	3.72 3.00	0.22 0.19	0.17 0.14	0.054 0.068	0.042 0.051
Difference			−0.73†	−0.72†	−0.03†	−0.03†	0.014†	0.009†

*Significant.
†Highly significant.
‡No sample available for 1917.

TABLE 2.—*Correlation between original organic matter and nitrogen content of soils and the losses of these constituents, respectively.*

Soil treatment	Soil series	Rotation, years	Degrees of freedom	Correlation coefficients (r)	
				Between original content and loss of organic matter	Between original content and loss of nitrogen
None	Clarion and Webster	2, 3, and 5	6	−0.719*	−0.635
Crop residue, limestone, and rock phosphate	Clarion and Webster	2, 3, and 5	4	−0.924†	−0.921†
All treatments ..	Webster	5	22	−0.852†	−0.889†
None.	Webster	5	5	−0.635	−0.871†

*Significant.
†Highly significant.

All check plats in the 5-year rotation showed significant losses of organic matter, the average loss amounting to 18.2% (Table 4). On the treated plats there was no significant loss except on Webster soils high in organic matter (plats Nos. 930, 931, 1025, 1026, 1030, 1031, 1032, 1033). All the treated Webster soils originally containing more than 7% organic matter showed significant losses.

The average losses of organic matter from the check plats in the various rotations on Clarion soil were as follows: 2-year rotation, 16.1%; 3-year rotation, 11.7%; and the 5-year rotation, 10.2%. The original content of organic matter in the Clarion soils was about 4%. The average loss from the Webster soil on the check plats of the 5-year rotation (plats Nos. 934, 1010, 1012, 1022, 1024, 1034) was about 19%, but the original content was 7.3%.

Correlations between original organic matter content and loss were determined on no-treatment plats and on plats that received crop residue, lime, and rock phosphate, regardless of soil type and rotation. Correlations were also made between original organic matter content and losses on the plats of the 5-year rotation, regardless of soil treatment, and on the no-treatment plats of the 5-year rotation on Webster soil. The data are presented in Table 2. The correlations were found to be significant or highly significant except with the no-treatment plats on Webster soil in the 5-year rotation. The coefficient of correlation of the latter was quite high and probably would have been significant if more samples had been available. These correlations help to show that the larger the amount of organic matter, the larger is the loss. They give the highly significant losses of organic matter which occurred on the Webster soil of the 5-year rotation, regardless of soil treatment, for these plats contain a large amount of organic matter.

NITROGEN CHANGES

The data obtained on nitrogen losses from the plats in three rotations are presented in Tables 1, 3, and 5. The tests of significance of gains or losses are given in Table 2.

TABLE 3.—*Changes in contents of organic matter, nitrogen, and phosphorus from 1917 to 1937 in soil of variously treated plats under corn, oats, and clover rotation.*

Treatment	Plat No.	Year sampled	Organic matter, %			Nitrogen, %			Phosphorus, %		
			Block III-A	Block III-B	Block III-C	Block III-A	Block III-B	Block III-C	Block III-A	Block III-B	Block III-C
None	817; 822 823; 828 829; 834	1917 1937	4.06 3.60	3.69 3.20	6.18 5.51	0.19 0.16	0.17 0.14	0.28 0.25	0 039 0.037	0.037 0.033	0.043 0.046
Difference			−0.46†	−0.49†	−0.67†	−0.03†	−0.03†	−0.03†	−0.002	−0.004	0.003
Manure and limestone	818; 824 830	1917 1937	3.58 3.42	4.28 3.44	6.91 6.56	0.18 0.16	0.20 0.17	0.30 0.26	0.035 0.037	0 038 0.036	0.044 0.046
Difference			−0.16	−0.84†	−0.35	−0.02*	−0.03†	−0.04	0.002	−0.002	0.002
Manure, limestone, and rock phosphate	819; 825 831	1917 1937	3.68 3.69	——‡ 3.14	——‡ 7.22	0.18 0.17	——‡ 0.15	——‡ 0 29	0.038 0.058	——‡ 0.064	——‡ 0.081
Difference			0.01			−0.01			0.020†		
Crop residues and limestone	820; 826; 832	1917 1937	3.89 4.13	——‡ 2.81	——‡ 7.75	0.19 0.18	——‡ 0.14	——‡ 0.33	0.039 0.040	——‡ 0.030	——‡ 0.055
Difference			0.24			−0.01			0.001		
Crop residues, limestone, and rock phosphate	821; 827; 833	1917 1937	4.54 4.47	2.78 2.70	——‡ 7.05	0.21 0.20	0.14 0.11	——‡ 0.31	0.041 0.058	0.033 0.054	——‡ 0.075
Difference			−0.07	−0.08		−0.01	−0.03†		0.017†	0.021†	

*Significant.
†Highly significant.
‡No sample available for 1917.

Most plats in the 2-year rotation showed significant losses of nitrogen even where treatments of manure or crop residues were made, and all check plats showed significant losses. In the 3-year rotation all check plats showed significant losses, but only three out of seven treated plats showed significant losses.

The check plats in the 5-year rotation showed significant losses of nitrogen in all cases. On treated plats on Clarion soil the losses, in general, were not significant, but on the treated Webster soils high in nitrogen significant losses occurred. The average loss from 10 treated plots on Webster soil containing originally more than 0.3% nitrogen was 18%, whereas the average loss from 12 plats on Clarion soil which received various treatments and contained less than 0.2% nitrogen was 6.4%. Thus, it is evident that the losses of nitrogen are much greater on soils originally containing high amounts of nitrogen. The gains of nitrogen in certain plats of block V-A of the 5-year rotation are probably due to the fact that these plats had been in alfalfa 2 years prior to the sampling of the soil and were in alfalfa when sampled.

The average loss of nitrogen from the check plats of the 2-year rotation on Clarion soil was 21 5%; from those of the 3-year rotation, 13.4%; and from those of the 5-year rotation, 10%. The original nitrogen content was about 0.2% in each rotation. The average loss from the check plats on Webster soil of the 5-year rotation was 18.2% and the average original content was 0.35%.

The correlations between original nitrogen content and loss of nitrogen determined for the same plats as were used in determining the correlation between organic matter content and loss are presented in Table 2. The coefficients of correlation, like those for organic matter, were significant, with one exception, and this one was quite large and probably would have been significant if more samples had been available.

TOTAL PHOSPHORUS CHANGES

The results for total phosphorus and the tests of significance of gains or losses are given in Tables 1, 3, and 6. The losses of total phosphorus, in general, were insignificant, and most of these which were significant were on Webster soil where the original content was high. The gains of total phosphorus were highly significant in every case where rock phosphate was applied, and were significant in a few cases where superphosphate was added. The losses from the soils which received manure alone or manure plus lime were, in general, less than from those receiving crop residues or no treatment. In several cases the plats receiving manure showed slight gains. These apparent slight gains or losses of phosphorus may be misleading since it is certain that the content should be lower after crops have been removed for 20 years. A partial explanation probably lies in the facts that (a) crops take up phosphorus from the subsoil and leave a portion of this in the surface soil as crop residues, and (b) erosion has no doubt removed some surface soil from the plats with the result that some of the layer originally below 6 inches has become incorporated with the plow layer.

TABLE 4.—*Changes in content of organic matter in soils of variously treated plats in a 5-year rotation, 1917–37.*

Treatment	Plat No.	Year sampled	Percentage organic matter†				
			Block V-A	Block V-B	Block V-C	Block V-D	Block V-E
None	912; 917; 922; 924; 929; 934; 1000; 1005; 1010; 1012; 1017; 1022; 1024; 1029; 1034	1917 1937	3.09 2.77	7.32 5.35	5.24 4.68	4.48 4.06	7.34 6.49
Difference........			−0.32*	−1.97†	−0.56†	−0.42†	−0.85†
Manure	913; 925 1001; 1013; 1025	1917 1937	——‡ 2.96	3.48 3.42	4.51 4.55	3.67 3.51	6.35 5.65
Difference.........				−0.06	0.04	−0.16	−0.70†
Manure and limestone	914; 926 1002; 1014; 1026	1917 1937	2.97 2.63	——‡ 4.31	3.87 4.12	3.67 3.30	7.21 6.58
Difference.........			−0.34		0.25	−0.37	−0.63†
Manure, limestone, and and rock phosphate	915; 927 1003; 1015; 1027	1917 1937	——‡ 2.73	5.83 5.49	3.83 3.89	3.88 3.65	6.33 6.51
Difference..........				−0.34	0.06	−0.23	0.18

Manure, limestone, and superphosphate	916; 928	1917	3.21	6.51	4.51	4.52	—‡
	1004; 1016; 1028	1937	3.16	6.05	4.48	4.32	6.20
Difference..........			−0.05	−0.46	−0.03	−0.20	
Crop residue	918; 930	1917	3.81	8.06	4.77	3.33	9.39
	1006; 1018; 1030	1937	3.66	7.09	4.70	3.42	7.33
Difference..........			−0.15	−0.97†	−0.07	0.09	−2.06†
Crop residue and limestone	919; 931	1917	3.84	7.54	4.92	3.73	9.96
	1007; 1019; 1031	1937	3.53	6.82	4.79	3.55	8.10
Difference..........			−0.31	−0.72†	−0.13	−0.18	−1.86†
Crop residue, limestone, and rock phosphate	920; 932	1917	3.65	6.66	—‡	4.67	10.18
	1008; 1020; 1032	1937	3.48	6.24	5.43	4.41	8.70
Difference..........			−0.17	−0.42		−0.26	−1.48†
Crop residue, limestone, and superphosphate	921; 933	1917	3.66	6.75	5.85	5.34	10.85
	1009; 1021; 1033	1937	3.37	6.51	5.61	5.03	8.60
Difference..........			−0.29	−0.24	−0.24	−0.31	−2.25†

*Significant.
†Block A was in alfalfa, 1935–37; B, 1930–34; C, 1915–19; D, 1920–24; E, 1925–29. Highly significant.
‡No sample available for 1917.

TABLE 5.—*Changes in nitrogen content of soils of variously treated plats in a 5-year rotation, 1917–37.*

Treatment	Plat No.	Year sampled	Percentage nitrogen				
			Block V-A	Block V-B	Block V-C	Block V-D	Block V-E
None	912; 917; 922; 924; 929; 934 1000; 1005; 1010; 1012; 1017; 1022; 1024 1029; 1034	1917 1937	0.16 0.14	0.33 0.25	0.23 0.21	0.21 0 19	0.36 0.32
Difference..........			−0 02*	−0.08†	−0.02*	−0.02*	−0.04†
Manure	913; 925 1001; 1013; 1025	1917 1937	—† 0.15	0.17 0.16	0.22 0.20	0.16 0.17	0.29 0.25
Difference..........				−0.01	−0.02*	0.01	−0.04†
Manure and limestone	914; 926 1002; 1014; 1026	1917 1937	0.13 0.14	—† 0.19	0.18 0.19	0.17 0.16	0.32 0.27
Difference..........			0.01		0.01	−0.01	−0.05†
Manure, limestone, and rock phosphate	915; 927; 1003 1015; 1027	1917 1937	—† 0.14	0.26 0.24	0.19 0.19	0.17 0.17	0.29 0.28
Difference..........				−0.02*	0.00	0.00	−0.01

Manure, limestone, and superphosphate	916; 928; 1004 1016; 1028	1917 1937	0.16 0.16	0.30 0.26	0.23 0.20	0.21 0.21	——† 0.29
Difference..........			0.00	−0.04†	−0.03†	0.00	
Crop residue	918; 930 1006; 1018; 1030	1917 1937	0.17 0.18	0.37 0.31	0.22 0.21	0.19 0.15	0.50 0.36
Difference..........			0.01	−0.06†	−0.01	−0.04†	−0.14†
Crop residue and limestone	919; 931; 1007 1019; 1031	1917 1937	0.16 0.17	0 38 0.31	0.22 0.21	0.21 0.16	0.51 0.39
Difference..........			0.01	−0.07†	−0.01	−0.05†	−0.12†
Crop residue, limestone, and rock phosphate	920; 932 1008; 1020; 1032	1917 1937	0.17 0.17	0.31 0.29	——† 0.24	0.21 0.20	0.50 0.40
Difference..........			0.00	−0.02*		−0.01	−0.10†
Crop residue, limestone, and superphosphate	921; 933 1009; 1021; 1033	1917 1937	0.17 0.16	0.32 0.27	0.24 0.24	0.24 0.21	0.52 0.40
Difference..........			−0.01	−0.05†	0.00	−0 03†	−0.12†

*Significant.
†Highly significant.
‡No sample available for 1917.

TABLE 6.—*Changes in phosphorus content of soils of variously treated plats in a 5-year rotation, 1917–37.*

Treatment	Plat No.	Year sample	Percentage phosphorus				
			Block V-A	Block V-B	Block V-C	Block V-D	Block V-E
None	912; 917; 922; 924; 929; 934 1000; 1005; 1010; 1012; 1017; 1022; 1024; 1029; 1034	1917 1937	0.032 0.032	0.045 0.041	0.041 0.038	0.039 0.036	0.069 0.057
Difference..........			0.000	–0.004*	–0.003	–0.003	–0.012†
Manure	913; 925; 1001 1013; 1025	1917 1937	——‡ 0.035	0.032 0.035	0.038 0.039	0.035 0.035	0.047 0.040
Difference..........				0.003	0.001	0.000	–0.007*
Manure and limestone	914; 926; 1002 1014; 1026	1917 1937	0.030 0.033	——‡ 0.036	0.034 0.037	0.036 0.036	0.056 0.042
Difference..........			0.003		0.003	0.000	–0.014†
Manure, limestone, and rock phosphate	915; 927; 1003 1015; 1027	1917 1937	——‡ 0.055	0.043 0.084	0.039 0.063	0.051 0.064	0.064 0.088
Difference..........				0.041†	0.024†	0.013†	0.024†

Manure, limestone, and superphosphate	916; 928; 1004 1016; 1028	1917 1937	0.032 0.039	0.043 0.047	0.037 0.044	0.043 0.044	——‡ 0.055
Difference..........			0.007*	0.004	0.007*	0.001	
Crop residue	918; 930; 1006 1018; 1030	1917 1937	0.034 0.034	0.051 0.047	0.038 0.037	0.033 0.031	0.060 0.062
Difference..........			0.000	−0.004	−0.001	−0.002	0.002
Crop residue and limestone	919; 931; 1007 1019; 1031	1917 1937	0.037 0.035	0.053 0.051	0.042 0.037	0.035 0.034	0.088 0.075
Difference..........			−0.002	−0.002	−0.005	−0.001	−0.013
Crop residue, limestone, and rock phosphate	920; 932; 1008 1020; 1032	1917 1937	0.038 0.050	0.054 0.090	——‡ 0.068	0.049 0.058	0.113 0.130
Difference..........			0.012†	0.036†		0.009†	0.017†
Crop residue, limestone, and superphosphate	921; 933; 1009 1021; 1033	1917 1937	0.035 0.037	0.045 0.099	0.040 0.045	0.043 0.042	0.095 0.091
Difference..........			0.002	0.054†	0.005	−0.001	−0.004

*Significant.
†Highly significant.
‡No sample available for 1917.

SUMMARY

A composite sample of soil was taken from each plat of the 2-, 3-, and 5-year rotation experiments involving various manurial treatments at the Agronomy Farm of the Iowa Agricultural Experiment Station in 1917. These plats were sampled again in 1937, taking three composite samples from each plat. The samples taken in 1917 and those taken in 1937 were analyzed in 1937 for organic matter, nitrogen, and total phosphorus.

A statistical analysis was made to test the significance of the gains or losses of organic matter, nitrogen, and phosphorus of each plat of the three rotations. Correlations between original organic matter and nitrogen contents and the losses of these constituents were determined.

The data available were not sufficient to make as many tests as desired. Nevertheless, the following conclusions are believed warranted:

1. The losses of organic matter and nitrogen were less with the 3- and 5-year rotations than with the 2-year rotation. The average loss of organic matter on Clarion loam where manure was not applied was 16.2% with the 2-year rotation, 11.7% with the 3-year rotation, and 10.2% with the 5-year rotation. On the Webster silt loam there was a loss of 19% with the 5-year rotation.

2. The loss of nitrogen in the Clarion loam, average of all checks, was 21.5% with the 2-year rotation; 13.4% with the 3-year rotation; and 10.0% with the 5-year rotation. In the Webster silt loam the loss was 18.2% with the 5-year rotation.

3. The decreases in organic matter and nitrogen where manure was applied were much less than where crop residues were returned.

4. In general, the losses of total phosphorus were insignificant. The losses from soils treated with manure alone or manure and lime were generally less than from the check plats or the plats treated with crop residues. The soils treated with rock phosphate showed highly significant gains in phosphorus. The losses of phosphorus from the untreated soils were less than the amounts of phosphorus removed in the crops during the period of the experiment, indicating an accumulation of phosphorus in the surface soil from the residues returned.

5. In most cases there were found to be highly significant correlations between original organic matter and nitrogen contents and the losses of these constituents. The larger the original contents, the larger were the losses.

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THE USE OF FORAGE-ACRE REQUIREMENTS IN RANGE SURVEYS[1]

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REGARDLESS of the detail involved in taking inventory of the grazing resources of a range, or of the accuracy of the work, the data obtained have only limited value without a knowledge of the number of forage acres required to graze an animal unit for a given period.[3] Such an inventory, or range survey, tabulates its findings in forage acres of feed available. The forage-acre requirement, here also referred to in abbreviated form as F.A.R., provides a measuring stick for adjusting the number of animals to the forage resources of the range as determined by the survey.

Forage acres of available feed cannot readily be converted into grazing capacities without employing forage-acre requirement figures. Furthermore, such conversions cannot be made correctly without the proper forage-acre requirements. It is evident, therefore, that F.A.R. studies should be conducted with great care and accuracy.

Range surveys have been made in the past on areas for which no forage-acre requirement figures were available. In certain of these cases, a tentative rate of stocking was proposed that was later modified as subsequent improvement or deterioration of the range required. Such a method of attempting to apply the results of a forage survey is little better than proceeding without any survey data.

A second method of limited applicability, that has been used in many instances in the absence of a forage-acre requirement figure, might be called the direct stocking method. This involves obtaining grazing capacity figures on a pasture of known area that appears to have been properly stocked, and applying this same rate of stocking to other essentially similar areas. The disadvantage of this method, as compared with use of a definite forage-acre requirement, is that no inventory of the forage is taken and, consequently, the rate of stocking determined can be applied only to areas that seem to have about the same grazing capacity.

A forage-acre requirement, on the other hand, can be applied over a much wider range of conditions, its applicability not being limited

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[3]Definitions used by the U. S. Soil Conservation Service:

Forage Acre: Range land in the amount necessary to furnish the equivalent of 1 acre completely (10/10) covered with vegetation that is 100% palatable. The number of forage acres in a type is obtained by multiplying the number of surface acres by the forage factor.

Forage factor: The figure arrived at by multiplying the palatability of a type by the average density.

Forage-acre requirement: The number of forage acres necessary to support and maintain an animal for a definite period of time.

by amount of available forage. The F.A.R. method, therefore, is relatively flexible and has a broad application as contrasted with the direct stocking method.

As long as the type and amount of forage remains the same, year after year, the forage-acre requirement will not vary appreciably on a given area, although it may vary widely from one locality to another, even on adjacent areas. For example, a forage acre on a grass range may not, and probably will not, have the same feeding value as a forage acre on a browse range. This fact often makes it difficult to employ fixed forage-acre requirement figures over legally delineated areas (sections or townships).

In surveying areas to determine forage-acre requirements, only perennials usually are included in the forage inventory. Annuals can be included in certain instances, but because of their ephemeral character and the difficulty of estimating correctly densities and composition, their inclusion in the estimates may be accompanied by a degree of error greater than would obtain were they omitted. Regardless of whether or not annuals are included, the degree of grazing they are permitted to receive will depend on the type of vegetation that should be maintained on the area. For example, on ranges where annual species have invaded as a result of improper management, and where perennials should be restored, use of the annuals should be sufficiently light not to interfere with the desired revegetation. On range lands of the type often encountered in Arizona and New Mexico, on the other hand, where annuals may comprise a natural seasonal phase of the vegetation even under proper utilization, the degree of grazing pressure allowed may be based on perpetuation of annual rather than perennial species.

When annuals are not included in the grazing surveys made on the areas to which the forage-acre requirement is to be applied, they likewise must be omitted in determining the forage-acre requirement. To do otherwise would not only be a waste of time; it would give erroneous results indicating a higher grazing capacity than actually obtained on the area to which the forage-acre requirement was to be applied.

Similarly, it is not always necessary to consider volume growth of grasses or other vegetation in making either range surveys or F.A.R. studies. It will be noted that this touches on a point that is much discussed in connection with range surveys, namely, the allowance that should be made to provide for volume growth. It is true that the volume may not be constant, even on the same area in different years. This factor will be of little consequence, however, provided the volume growth on the area to which the forage-acre requirement is to be applied is evaluated in relation to the probable average volume growth over a period of years, which, of course, presupposes that the F.A.R. study is based on information that permits a correct evaluation of average volume production for that particular type.

The term forage-acre requirement has been objected to on the ground that an animal will require as many forage acres on one type of range as on another. The suggestion has been made, therefore, that the word "requirement" should be replaced by "allowance"

in all references to the number of forage acres needed to support a given animal for a given length of time. The basis for this suggestion seems to lie largely in the opinion that any one forage acre is the equivalent of any other forage acre in feeding value.

The fallacy of this reasoning is readily apparent when we consider such contrasting types of forage as annual weeds and perennial grasses. Such entirely dissimilar types of forage should no more be expected to have the same calorific value than would a pound of lettuce and a pound of beefsteak. Similarly, in view of the fact that volume growth generally does not enter into grazing capacity determinations until after the F.A.R. has been applied, it would obviously be incorrect to assign the same forage-acre requirement to blue grama or other short-grass range as to one supporting wheatgrass or a similar type of vegetation.

It is true, that, in some instances, different forage-acre requirements should be set up, not on a basis of different feeding values in a given unit of forage, but on a basis of forage potential, slope, or other factors. In such cases, it might be more nearly correct to apply the term forage-acre allowance than forage-acre requirement. Even so, as "requirement" is in common use today and because this use is technically correct in many instances, it would seem that the term should continue to be used in this way.

Vegetation, soil, slope, and climate must be the principal criteria employed in determining the areas to which certain forage-acre requirements are to be applied. However, as vegetation is the product, in large part, of soils and climate, it is often possible to determine the area of application of a given forage-acre requirement largely on a basis of vegetation. Additional factors, somewhat different in nature, are sometimes involved, requiring use of separate F.A.R. figures. The principal factors that necessitate the use of more than one forage-acre requirement are, essentially, the following:

1. *Amount of unmeasured forage present.*—This may result from growth of annuals, a longer than average growing season, recurrent growth on perennials, or volume growth. The greater the amount of unmeasured forage present, the lower the forage-acre requirement. The effect of annuals is particularly evident in the brushy desert ranges of the Southwest, where the so-called "winter and summer annuals" provide large amounts of feed for short periods.

2. *Differences in nutrient value of different types of forage.*—Differences in nutrient value may be the result of several factors, one of the more important of which is soil. Insofar as dissimilar soils produce different kinds of vegetation varying in nutrient values and these differences can be determined, unlike soils may require different forage-acre requirements.

3. *Condition of range.*—As forage-acre requirement figures are based on ranges managed on a sustained-yield basis, deteriorated areas will require higher forage-acre requirements to allow for recovery. Wherever possible, of course, F.A.R. determinations should be made on properly grazed ranges. In some instances, however, such areas are not available. A forage-acre requirement obtained on deteriorated rangelands, if applied without modification to similar

areas, presumably will tend to maintain those ranges at their deteriorated level. Therefore, if the vegetation and grazing capacity of these lands is to be restored to the former level, application of a somewhat higher F.A.R. than was actually obtained in the study will be necessary. This item, on the other hand, may be handled for individual types or for the range as a whole, by applying a cut to the gross animal months of forage instead of by an increase in the forage-acre requirement.

4. *Variations in density and composition estimates made by different survey parties.*—Inasmuch as grazing surveys are based in large part on estimates, and as no absolute standard is available with which to check these estimates, different survey parties may vary the number of forage acres on a given area. For this reason it is essential that each survey party either work out its own forage-acre requirements, or correlate its survey with those of the other agencies involved. This correlation should be made with sufficient care to make it possible to determine the modification of one agency's forage-acre requirement necessary to permit its application to survey data obtained by the alternate agency.

5. *Differences in elevation, exposure, and precipitation.*—Differences in vegetation that normally occur at different elevations or exposures often are largely the result of variations either in the moisture balance or in the total precipitation falling on the area. Where such vegetal variations occur, a change in the forage-acre requirement will usually be necessary.

6. *Differences in slope.*—Steep slopes, in general, are more erodible than gentle ones and, because they are also usually less accessible, are less heavily grazed. The difference in permissible grazing use is usually handled on small areas by assigning a cut to the steeper slopes; but where this has not been done, or on ranges which, because of slopes, are markedly more erodible than others, a higher F.A.R. should be employed than would be used on more nearly level range.

7. *Variations in forage-production potentials of different soils.*—Certain soils may produce a greater volume of forage and consequently should have a lower forage-acre requirement than other poorer soils that may be immediately adjacent. This item, like items 3 and 6, can be handled by applying a cut to the gross animal months of forage rather than by an increase in the forage-acre requirement.

8. *Erodibility of soils.*—Ranges with highly erodible soils will generally need a higher forage-acre requirement than those where soils are less likely to erode. However, where variations in erodibility of soils are caused by differences in degree of slope rather than by variations in soils, and where closeness of grazing is controlled by regulation of the number of forage acres allowed an animal unit on the area, there usually will be no correlation between forage-acre requirement and soil type, but rather between forage-acre requirement and slope. Occasionally, there may be a general correlation to broad soil types, but not to narrow ones.

9. *Grazing practices.*—Range utilized on a deferred or rotation grazing system usually will provide more forage than similar areas

that receive continuous use, and consequently should have a lower forage-acre requirement.

10. *Uniformity of forage utilization.*—On range with rough topography, inadequate water, or other local conditions preventing uniform utilization of all the forage, it may be necessary to use a higher forage-acre requirement than on otherwise similar, but more uniformly utilized range. A condition of this sort, however, can be, and usually is handled by assigning a cut to the gross forage acres.

The essential factors to be considered in making forage-acre requirement studies in the field are presented in the following outline:[4]

I. Selection of areas.
   A. The area studied should be typical of the area to which the forage-acre requirement will be applied as to type of vegetation, topography, and soil, and should be grazed by the same class of stock. Wherever possible the entire ranch, rather than a single pasture, should be used.
   B. Preferably the pasture should be in good condition.
      1. The examiner will be guided by the following indicators of good condition:
         a. Good density and vigorous condition of the desirable forage species. Condition judged by color, general appearance, and height of growth.
         b. Absence of accelerated soil erosion.
         c. Absence of extensive areas overrun by annual weeds and grasses or by other plants indicating vegetational deterioration.
         d. Lack of evidence of local overgrazing resulting from poor distribution of water and salt or other factors.
      2. In an area where it is not possible to locate a suitable pasture in good condition because of overgrazing, drought, rodent damage, or poor management, the examiner in the field must appraise the cause, nature, and extent of the unsatisfactory condition in order to make adjustments required to place the study on a satisfactory basis. On overgrazed ranges, the examiner must judge the extent of overgrazing. Factors that appear trivial may aid in evaluating the condition of the range and have a bearing on the F.A.R.
   C. The pasture should be of sufficient size to constitute a reliable sample of the area. The most satisfactory size of pastures on which dependable data can be assembled is probably between 640 and 5,000 acres.
   D. The pasture should be fenced in order to control numbers of livestock and thus eliminate influences that might affect the reliability of the resulting data and conclusions.

[4]Adapted in part from Instructions for Collection of F.A.R. Data on Selected Pastures (manuscript), by L. R. Albee, Soil Conservation Service, Ft. Meade, South Dakota.

II. Records of actual stocking.

A. The examiner should select a pasture for study on which actual stocking records have been kept for a number of years.

1. Records kept for 10 years or longer are best, yet most consideration should be given to significant trends of recent years.
2. Four years of reliable records should be considered the acceptable minimum.
3. Written records are most desirable, but in the absence of these, good memory records can be used.

B. The records should include the following data:

1. Number of head of each class and age of livestock grazed on the unit (horses, cows, yearling steers, and sheep). This information is essential in converting the livestock to a common unit.
2. Length of the grazing period each year.
   a. Date that stock were put on pasture.
   b. Date of removal.
3. Reasons for variations in number of animal units grazed, or in length of grazing period when the departure from the average is significant.
   a. The most desirable stocking records are those having the least yearly departure from the average over a period of years, because such a record will generally indicate that the stockman, to some extent, has systematized his grazing operations.
   b. During seasons of general drought or some unfavorable economic condition, the exact circumstances that caused any significant departure should be ascertained. This is an important item about which the examiner should obtain all the information possible.
4. Amount of supplementary feed supplied.
   Where supplementary feed has been furnished, the feeding value of this feed should be taken into consideration in determining the dependence of the animals on the range forage.

In collecting forage-acre requirement data, the information given below should be the minimum obtained: (1) Forage resources of area, expressed in forage crops; (2) stocking records of area, converted to animal units; and (3) supplementary feed furnished during grazing season.

The following equation may be useful in calculating forage-acre requirements: Assuming availability of a 5-year stocking record, the average monthly use over this period should be obtained, $\frac{A}{B} = C$, where A = number of forage acres; B = cow months of use; and C = monthly forage-acre requirement. In obtaining B, the animal months of supplementary feed furnished should be subtracted from the total

animal months of feed obtained from both grazing and feeding before calculating the forage-acre requirement.[5]

An example of the data obtained may be summarized and calculated as follows:

20 cows	@ 1.0	Animal Units	=	20.00	Cow Units	
1 bull	@ 1.25	" "	=	1.25	" "	
10 yearlings	@ .75	" "	=	7.50	" "	
10 calves	@ .6	" "	=	6.00	" "	
50 mixed	@ .8	" "	=	40.00	" "	
3 horses	@ 1.25	" "	=	3.75	" "	
3 mares	@ 1.25	" "	=	3.75	" "	
Total......................				82.25	Cow Units	

82.25 cow units × length of time grazed (assume 7 months) = 576 cow months use. Postulating 119 forage acres of feed available:

$$\frac{\text{119 forage acres}}{\text{576 cow-months use}} = 0.2 \text{ forage acres required per cow month, i.e.,}$$

a monthly forage-acre requirement of 0.2.

[5]A breeding cow is considered as one animal unit and values are assigned to all other ages and classes of livestock based on estimates of the relative amounts of forage consumed by them.

EFFECT OF LEVEL TERRACES ON YIELD AND QUALITY OF PASTURAGE AND WATER CONSERVATION[1]

H. R. BENFORD AND D. G. STURKIE[2]

THE amount and distribution of rainfall are important factors influencing the amount and seasonal distribution of pasture growth. This is especially true on upland sandy soils of the South where runoff and percolation are sometimes so rapid that moisture becomes a limiting factor in pasture growth even during relatively short periods of drouth. Mayton (3)[3] found that the average seasonal yield of pasturage was associated very closely with the average distribution of rainfall with an approximate 20-day time lag.

Studies by Greene (1), using closely-spaced terraces, 40 inches apart, showed that level terracing was effective in preventing all runoff for the season except for excessive rains which overflowed the terraces. According to his observations, more forage was produced per acre where level terraces were used and cattle preferred the pasturage on the terraced area to that on the unterraced.

Since moisture is often a limiting factor in pasture production on upland soils in the South, it is desirable to know some practical means of conserving moisture and thus increasing production. The experiment herein reported was therefore conducted to determine the effect of level terraces on water conservation and on yield and production of pastures. These studies were made at the Alabama Agricultural Experiment Station, Auburn, Alabama.

EXPERIMENTAL

An area of Norfolk sandy soil with a slope of 15 to 20% was selected. This area had been in pasture for several years but was supplying very little grazing because of its low fertility (Fig. 1). By making a small drain down the slope the pasture was divided into two approximately equal areas. One area was level terraced and the other was left unterraced (Fig. 2). On the terraced area about twice the number of terraces was built that would have ordinarily been used for cultivated fields (Fig. 3). These terraces were of the Nichols (2) type with a base of from 16 to 20 feet and a depth of about 18 inches in the center of the channel. One end of each terrace was closed and the other end was so constructed that after the channel was filled, the excess water drained into a cistern where it was measured. Each terrace had a holding capacity of about 6 cubic feet of water per linear foot, making it possible to hold about a 2-inch rainfall on the area.

The terraced area was prepared for seeding by breaking to a depth of about 4 to 6 inches. It was then subsoiled to a depth of about 14 inches between terraces to increase the absorption of water. The unterraced area was prepared by breaking to a depth of 4 to 6 inches and was not subsoiled.

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[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Authorized for publication by the Director. The cooperation and suggestions of the Department of Agricultural Engineering, especially of Professor M. L. Nichols, for designing and supervising the construction of the terraces, are gratefully acknowledged. Received for publication July 17, 1940.

[2]Graduate Assistant and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 767.

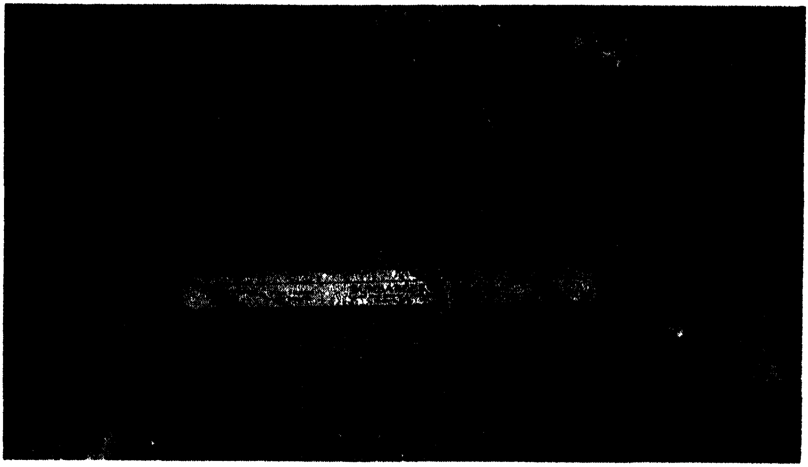

FIG. 1.—View showing condition of sod on untreated area. Compare with Fig. 4.

On March 4, 1935, basic slag (8% P_2O_5) was broadcast over both areas at a rate of 1 ton per acre and disked in thoroughly. On March 16, 1935, the entire pasture was seeded to a mixture of Dallis grass (*Paspalum dilatatum*), 19 pounds per acre; common lespedza (*Lespedza striata*), 17 pounds per acre; Kentucky bluegrass (*Poa pratensis*), 22 pounds per acre; and hop clover (half *Trifolium dubium* and half *Trifolium procumbens*), 2 pounds per acre. The seed were sown broadcast and then covered with a section harrow. By April 16, 1935, there was a good stand of all plants seeded. At this time an application of 100 pounds per acre of nitrate of soda was broadcast uniformly over each area.

An application of superphosphate (16% P_2O_5), broadcast on both areas at a rate of 400 pounds per acre on September 17, 1938, was followed on October 17, 1938, by a seeding of lappa clover (*Trifolium lappaceum*), 2 pounds per acre, and white clover (*Trifolium repens*), 3 pounds per acre.

Records were taken throughout 1938 and 1939 during which time the flora in the spring was largely hop clover with some white clover and Kentucky bluegrass, and in the summer was Dallis grass and common lespedeza. The pasture was

FIG. 2.—General view of pasture showing terraced area (left) and unterraced area (right), placement of cages, drain separating the two areas, and erosion on the lower side of the unterraced area.

FIG. 3.—View of terraced area showing cages, terraces, and bare strip along the top of terraces.

grazed with cattle continuously throughout the study, and also mowed at intervals for weed control. Observations were made concerning the general condition of each area as to weeds and erosion.

To determine the yield and quality of pasturage, wire cages were distributed systematically over both terraced and unterraced areas. All cages were 3 feet by 18 feet and were constructed with a hinge on the base rails so that they could be placed across terraces (Fig. 3). Plant material was cut with a lawn mower when the plants under the cages reached a height of 4 to 5 inches. The green material was weighed immediately, and a ½-pound sample saved for analysis. The pastur-

FIG. 4.—View showing grazed and ungrazed areas. *Left*, ungrazed; *right*, grazed Compare with Fig. 1.

age on an area of equal size just outside each cage was cut, the material weighed, and its weight subtracted from the weight of that under the cage in order to determine the amount consumed by livestock (Fig. 4). After each cutting the cages were moved to new places. Samples that were saved for analysis were oven-dried (100° F) and determinations were made of dry matter and total nitrogen.

To determine the influence of level terraces on water conservation, measurements of runoff from both terraced and unterraced areas were recorded by Stevens water level recorders which were placed in cisterns.

RESULTS AND DISCUSSION

A good stand of plants was present on both the terraced and unterraced areas throughout the test. The rainfall was normal in April, July, and September; below normal in May and June; and above normal in August. Thus an excellent opportunity was afforded to study the effectiveness of moisture conservation. From Table 2 it may be seen that a period of high rainfall in April was followed by one of low rainfall in May and June and one of high rainfall in August by one of low rainfall in September.

YIELD AND SEASONAL GROWTH

The data in Table 1 show that there was practically no difference in the total yield of dry matter produced per acre under terraced and unterraced conditions.

PERCENTAGE OF DRY MATTER AND PROTEIN

There was little difference in the average percentage of dry matter produced on the terraced and unterraced areas (Table 1). During dry seasons, however, there was some tendency for the moisture content of plants to be higher on the terraced than on the unterraced area. This was probably caused by the high moisture content of plants growing in the terrace channel, which in many cases were undesirable weeds rather than edible plants.

There was little difference in the average protein content of the dry matter from the terraced and unterraced areas.

PERCENTAGE DRY MATTER CONSUMED

Data in Table 1 show that for the season as a whole there was little difference in percentage dry matter consumed from the two areas. The larger percentage consumed in April from the unterraced area was probably caused by the presence of a higher percentage of hop clover on the unterraced area than on the terraced area, and to the fact that there was little grazing above terraces during this month because of surface water immediately above terraces and settlings on plants after the water had evaporated or had percolated into the soil. Except for the early spring period, percentage consumption seemed to vary inversely with yields under both terraced and unterraced conditions. During June, July, and September more material was consumed than was produced which means that part of the pasturage consumed during these months grew previously. The surplus production of high-producing periods was utilized during low-producing periods (Fig. 5).

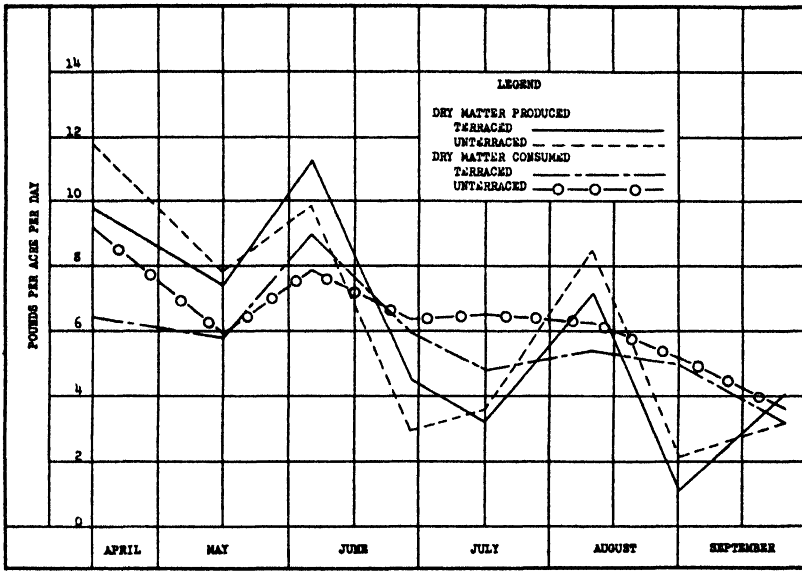

FIG. 5.—Average daily acre yields of dry matter and average daily acre consumption of dry matter from terraced and unterraced conditions, 1938–39.

TABLE 1.—*Influence of level terraces on yield of dry matter, protein content, dry matter consumed, and seasonal growth of pasturage, 2-year average, 1938–39.*

Approximate cutting dates	Pounds of dry matter harvested per acre		Percentage dry matter		Percentage protein		Percentage dry matter consumed*	
	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced	Terraced	Unterraced
Apr. 15....	295	355	29.4	29.2	15.6	17.6	66.1	77.5
May 15....	227	237	27.3	31.0	15.0	15.2	76.7	75.6
June 5.....	248	217	25.3	30.1	12.9	12.9	75.8	76.5
June 28....	100	65	32.9	37.4	12.0	12.3	139.0	226.2
July 15 ...	55	62	34.6	35.6	12.7	11.3	149.0	180.6
Aug. 10....	186	221	24.4	23.7	13.4	12.7	75.3	74.7
Sept. 1.....	25	49	28.4	32.5	16.0	12.2	444.0	234.7
Sept. 25....	98	76	41.9	38.8	12.2	13.2	77.6	110.5
Total....	1,234	1,282	—	—	—	—	—	—
Average	—	—	28.3	29.6	13.9	14.4	89.5	92.9

*Percentage based on amount produced during the period under consideration.

WATER CONSERVATION

Data in Table 2 show the amount of water conserved by level terraces during the growing season of 1939. Pasture plants require from

425 to 550 pounds of water to produce 1 pound of dry matter (4, 5). Using 500 pounds of water as the amount required to produce a pound of dry matter, the terraced area should have produced 633 pounds above that produced by the unterraced area if all the water conserved had been utilized (Table 2).

TABLE 2.—*Rainfall and water losses by months during the growing season under terraced and unterraced conditions, 1939.**

Month	Rainfall		Water lost by runoff, pounds per acre		Pounds of water conserved per acre by level terraces	Theoretical increase possible in yield per acre from terracing, pounds†
	Inches	Pounds per acre	Terraced	Unterraced		
April	4.08	924,169	41,159	216,154	174,995	350
May	3.73	844,890	4,368	19,406	15,038	31
June	2.35	532,303	7,301	27,643	20,342	41
July	3.53	799,587	3,609	14,664	11,055	22
August	9.63	2,181,311	264,701	353,246	88,545	177
September	4.00	906,048	12,667	18,782	6,115	12
Total	27.32	6,188,308	333,805	649,895	316,090	633

*1938 results were not used because cisterns were out of order.
†This figure was determined by dividing the pounds of water conserved by 500. Five hundred pounds of water is the approximate amount required to produce a pound of dry matter.

Even though considerable water (about 50% of runoff) was conserved by level terraces, there was no increase in yield. This lack of increased yield under terraced conditions seemed to be due to three conditions. First, the water was conserved at a time when it was plentiful, at which time it was lost by evaporation from the surface and by percolation into the soil below the root zone where it was not available when needed by plants. Second, the water accumulated in a small area just above the terraces and had a tendency to silt and drown out pasture plants. Third, the tops of the terraces were subject to drouth, causing 2- to 3-foot bare strips along the tops of the terraces, as illustrated in Fig. 3.

These results indicate that there was little advantage in attempting to conserve moisture in humid climates by means of level terraces on upland sandy soils for the growth of shallow-rooted pasture plants. It seems, therefore, that the most logical solution would be to locate deep-rooted plants capable of growing on these soils.

GENERAL OBSERVATIONS

Weeds were more prevalent on the terraced area than on the unterraced area. The moisture conditions in the terrace channel probably accounted for the weed growth which crowded out the desirable pasture plants. Weeds on the terraced area were more difficult to control than on the unterraced area because of the difficulty of mowing over the terraces.

The indications were that the unterraced area will be seriously eroded in a few years if left unterraced, while no apparent erosion

was evident on the terraced area (Fig. 2). Although terracing did not increase production in this experiment, upland permanent pastures should be sufficiently terraced to prevent erosion.

SUMMARY

Results are reported of studies on the effect of level terraces, 16 to 20 feet wide at the base and spaced twice as close as ordinarily used, on yield and quality of pasturage and runoff from an upland Norfolk sandy soil of low fertility and 15 to 20% slope at Auburn, Alabama, during the 2-year period, 1938–39, inclusive.

The terraces reduced the runoff approximately 50% but were not effective in increasing pasture yields. They had little effect on percentage dry matter and percentage protein in the plants.

There was no decided difference in the percentage of dry matter consumed under terraced and unterraced conditions. Percentage consumption varied inversely with yields, indicating that the consumption curve may be smoothed out for the entire grazing season by properly stocking the pasture.

There were more weeds on the terraced area than on the unterraced area. Weed growth was luxuriant along the terrace channel.

Considerable erosion was noticeable on the unterraced area, indicating the need for terracing to control erosion. No appreciable erosion occurred on the terraced area.

On the basis of the results obtained in this study, it may be concluded that level terraces were not effective in increasing the pasturage on Norfolk sandy soil; however, the terraces were desirable for soil conservation.

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DISEASE INFECTION AND FIELD PERFORMANCE OF BIN- AND HANGER-DRIED SEED CORN[1]

BENJAMIN KOEHLER AND GEORGE H. DUNGAN[2]

ONE of the changes in the preparation of seed corn that took place on a wide scale when the production of hybrid seed corn developed as a specialized business, was the employment of hot-air-drying bins in place of ear-corn hangers for drying the seed. This change has resulted in a considerable economy of space and labor. The investigation herein reported was intended to determine whether this change has also resulted in an improvement in the quality of the seed. Two independent sets of experiments were conducted.

EARS BIN-DRIED BY PRODUCERS

At seed-corn harvesting time in 1936, 1937, and 1938, 20-ear samples of a number of different hybrids and varieties were collected from several producers and dried in Martin hangers located on the third floor of the Agronomy Building, University of Illinois South Farm, Urbana, Ill. Two such hangers are shown in the chamber in Fig. 2 Adequate ventilation was provided to facilitate the drying of the ears, and steam heat was supplied on very cold days. Conditions during the entire period of storage were believed to be favorable for seed corn. Seed cured and stored in this manner has been designated in this report as "hanger-dried" corn.

Seed of the same hybrids and varieties which had been cured in heated bins in the usual way and had been shelled, graded, and treated for disease control was furnished the next spring by the producers. The grade "medium flat" was used. This seed has been designated as "bin-dried" corn. Part of a small commercial processing plant is shown in Fig. 1.

Field tests of the performance of the two lots of seed corn from the respective collections were made in 1937, 1938, and 1939, on the Agronomy South Farm. Plots were 10 hills long and two rows wide. Ten plots of each entry were planted each year. The hanger-dried seed was treated with a fungicide to correspond with that used by the commercial producers. The hanger-dried corn was planted adjoining the bin-dried corn in all cases, so the trials may be said to be paired experiments. Three kernels were planted by hand in each hill. The field stand represents the percentage of kernels planted that produced plants in the field.

The results of the three years' test involving 19 different kinds of corn and 12 different bin driers show (Table 1) that the hanger-dried corn produced an average field stand of 93.9% compared with 92.1% for the bin-dried corn. In yield of grain the hanger-dried corn produced an average of 96.9 bushels an acre and the bin-dried corn, 93.7 bushels. The difference of 3.2 bushels an acre, though not large, was

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[2]Chief in Crop Pathology and Chief in Crop Production, respectively.

accompanied by odds of 713 to 1, according to Student's method, which may be considered significant.

In the tests made in 1937, four pairs of entries showed differences carrying odds of 30 to 1 or greater, and one of these was in favor of bin-dried corn. In 1938 two comparisons showed significant differences. One was in favor of bin-dried seed and the other in favor of hanger-dried seed. In 1939 all 10 comparisons showed a yield difference in favor of hanger-dried corn and 6 of them were accompanied by odds sufficiently large to indicate significance.

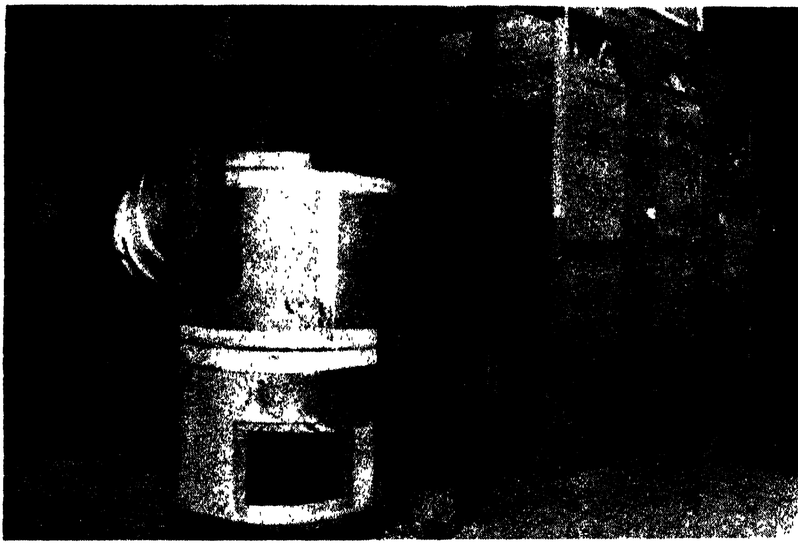

FIG. 1.—A small commercial seed corn drying plant of the bin type. This apparatus, including a five-horse power motor driven fan, takes care of eight bins, each holding 120 bushels of ear corn.

EARS DRIED IN EXPERIMENTAL CHAMBERS

METHODS

Seed ears.—Ears of two commercial hybrids were hand-picked from commercial seed-producing fields in 1937 and 1938 when the grain moisture was about 30%. The ears selected were above average in uniformity, size, and freedom from blemishes as compared to the field run. They were handled carefully to avoid injury to the seed coats and each hybrid was divided at random into three lots of 120 ears each to determine the effect of different rates of drying on internal seed infection.

Drying chambers.—Drying was accomplished in special chambers (Fig. 2). For rapid drying, a small stream of heated air was supplied and the temperature within the chamber was maintained at 106° F. Humidity was not controlled but averaged about 32% relative humidity during the four days in which the corn was dried from 30% grain moisture to 12%.

For a moderate rate of drying, the temperature was maintained near 70° F and the humidity was controlled at 65% relative humidity. The corn dried to 12% in four weeks.

TABLE 1.—*Performance of corn dried somewhat slowly on hangers under favorable conditions compared with corn dried quickly in artificially heated bins, Urbana, Illinois.*

Kind of corn	Drying plant No.	Field stand, %		Yield, bu. per acre			Odds
		Hanger dried	Bin dried	Hanger dried	Bin dried	Amount by which hanger-dried corn exceeded (+) or fell short (-) of bin-dried corn	
				1937			
Commercial Hybrid A	2	96.3	93.0	91.3	91.4	-0.1	1:1
Commercial Hybrid B	3	96.5	93.5	93.8	85.6	+8.2	1666:1
Illinois Hybrid 384	3	95.8	93.5	96.6	92.2	+4.4	30:1
Griffith Yellow Dent	4	94.3	97.0	93.9	88.1	+5.8	262:1
Murdock Yellow Dent	5	93.3	91.8	73.2	71.9	+1.3	5:1
Commercial Hybrid C	8	95.7	91.2	102.2	98.1	+4.1	18:1
Illinois Hybrid 582	8	96.8	95.2	105.8	105.6	+0.2	1:1
Illinois Hybrid 172	8	94.7	93.7	94.2	99.4	-5.2	49:1
Commercial Hybrid D	11	95.8	95.3	93.9	91.0	+2.9	8:1
Average.............		95.5	93.8	93.9	91.5	+2.4	20:1†

				1938			
Illinois Hybrid 960	1	90.0*	93.0*	104.7	111.0	−6.3	66:1
Indiana Hybrid 845	1	88.0*	93.0*	113.1	116.3	−3.2	5:1
Illinois Hybrid 582	2	93.0*	86.0*	115.5	106.0	+9.5	666:1
Average.............		90.3*	90.7*	111.1	111.1	0.0	———
				1939			
Illinois Hybrid 960	1	97.3	95.5	103.5	95.9	+7.6	344:1
Commercial Hybrid E	2	94.2	90.5	86.7	85.0	+1.7	4:1
Commercial Hybrid F	3	94.3	94.7	97.5	92.0	+5.5	216:1
Illinois Hybrid 751	6	88.8	92.5	94.8	92.4	+2.4	667:1
Commercial Hybrid G	7	92.3	80.7	96.4	89.0	+7.4	49:1
Commercial Hybrid H	8	95.0	94.2	88.8	86.5	+2.3	4:1
Commercial Hybrid C	9	95.8	85.8	101.6	93.3	+8.3	216:1
Commercial Hybrid I	10	85.8	87.5	94.3	88.8	+5.5	4:1
Commercial Hybrid J	11	95.8	95.0	94.1	90.8	+3.3	8:1
Commercial Hybrid K	12	96.3	93.2	96.8	91.2	+5.6	132:1
Average.............		93.6	91.0	95.5	90.5	+5.0	9999:1†
Grand average		93.9	92.1	96.9	93.7	+3.2	713:1†

*Percentage of strong seedlings on the germinator, rather than field stand.
†Odds calculated on the average.

For slow drying the temperature was kept at 70° F and the relative humidity at 86%. The corn was kept in this chamber for three months at the end of which time it still contained 17% moisture. It was then dried rapidly to 12%. Some ventilation was provided for each of the chambers.

The first lot simulated bin-drying conditions, the second lot was intended to represent first-class hanger-drying conditions as practiced by careful farmers and seedsmen who do not have forced hot-air drying equipment, while the third lot represented poor hanger-drying conditions.

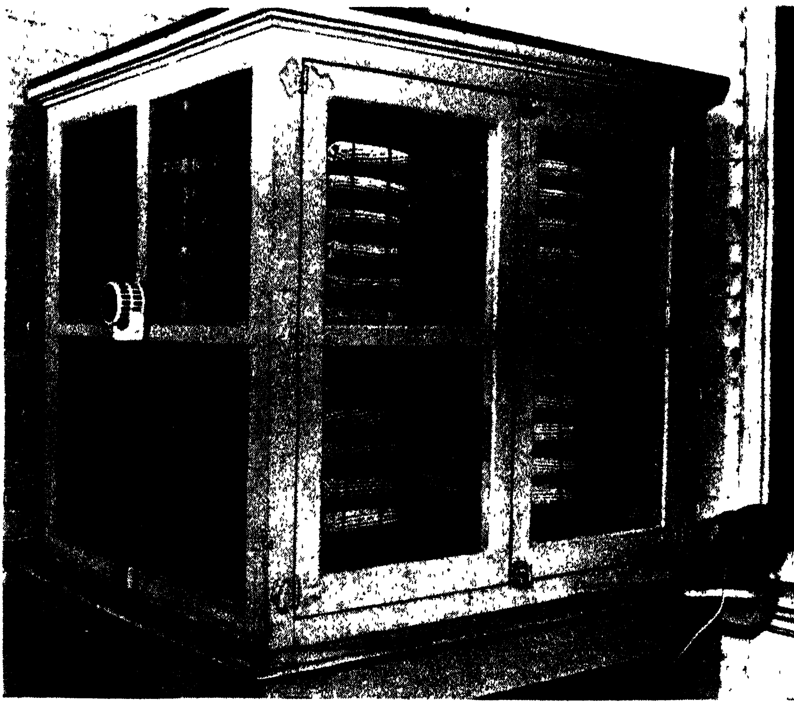

FIG. 2.—One of the experimental drying chambers used. It was equipped for temperature and humidity control, as well as for change of air. Picture shows 120 ears of each of two hybrids slow-dried in 1938.

After the ears were dry they were tipped and butted and eight kernels were removed in a spiral manner from end to end of each ear for determination of disease infection.

Infection determinations.—Seed infection may roughly be divided into two kinds, *viz.*, (a) total, that is, surface plus internal infection; and (b) the more deep-seated infections which remain after the seed has been surface sterilized. Total infection can probably best be determined by placing the unsterilized grain between wet sterilized muslins or fresh paper towels or blotters in a germinator. Results cannot always be read accurately because fast-growing surface contamimates may hide from view more important parasites. Nigrospora, for instance, can rarely be detected as a mycelial growth on a germinator but shows up very well in culture dishes (Fig. 3). *Fusarium moniliforme* (Table 5), *Penicillium*

species, and *Cephalosporium acremonium* readings are higher on unsterilized seed than on sterilized seed. No doubt some of the infection with these organisms is so superficial that it is killed by a surface disinfectant such as mercuric chloride or chlorine solutions.

Since the more deep-seated infections are more important than total infection and since the method is no doubt more accurate for comparative purposes, the percentages of kernel infection were determined by the surface sterilizing and plating method. A dish with eight kernels was prepared from each ear (Fig. 3).

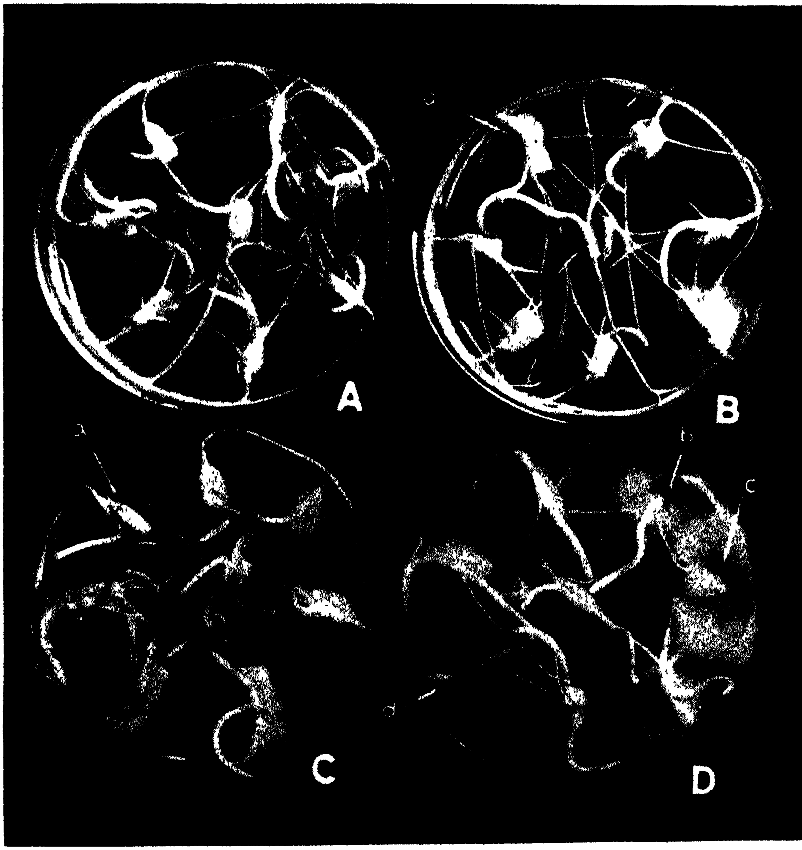

FIG. 3.—Testing for internal seed infection by the plating method. A, From ears dried in four days, 94.9% of the kernels tested free from infection. B, Dried in one month. C and D, Dried in three months. Names of fungi shown (a) *Cephalosporium acremonium;* (b) *Penicillium sp.;* (c) *Gibberella zeae;* (d) *Nigrospora sphaerica.* All other fungus colonies are *Fusarium moniliforme.*

Yield tests.—Yield tests were conducted on the University farm in hand-planted plots two rows wide by 16 hills long, three kernels per hill, 10 plots of each kind of corn. Acre yields were determined on a uniform moisture basis. Except where mentioned otherwise, the seed was treated with a good organic mercury disinfectant before planting.

DIFFERENCES IN DRYING AND FIELD PERFORMANCE

A composite sample from all the viable ears of each hybrid and of each of the three rates of drying was used in a field test (Table 2). This required only a small part of each ear and the remainder of the ear was available for other field tests (Table 4). A small number of ears had poor germination and were discarded.

The corn which was dried rapidly and that which was dried at a moderate rate produced crops with nearly identical field stands and yields of grain. None of the differences are statistically significant; but when the results from rapidly dried seed were compared with those from the slowly dried corn, there was a statistically significant difference three times in four (Table 2) in favor of the former.

TABLE 2.—*Effect of three different rates of seed drying on resulting field stand and acre yield of several yellow dent corn hybrids, Urbana, Illinois.*

Year*	Hybrid	Rate of drying	Relative humidity while drying, %	Field stand, %	Acre yield, bu.	Difference in yield between fastest and slowest dried seed, bu.
1938	Illinois 960	Rapid	32	97.0	92.1	
		Moderate	65	96.5	92.4	
		Slow	86	92.7	88.0	4.1†
1938	Nebraska 110	Rapid	32	95.4	89.5	
		Moderate	65	95.9	88.1	
		Slow	86	94.0	86.6	2.9
1939	Illinois 960	Rapid	32	93.9	104.4	
		Moderate	65	95.9	106.0	
		Slow	86	84.7	96.0	8.4†
1939	U. S. 13	Rapid	32	94.8	109.6	
		Moderate	65	95.1	107.9	
		Slow	86	82.3	98.0	11.6†

*Year in which field test was made. Seed ears harvested and dried in the previous fall.
†Statistically significant difference.

FUNGUS INFECTION IN SEED

Differences in rapidity of drying had a marked effect on internal fungus infection of the grain (Table 3, Fig. 3). Total fungus infection in corn dried at rapid, moderate, and slow rates was, respectively 5.1, 18.3, and 69.0% of the kernels. The prevalence of the first group of fungi in Table 3, namely, *Fusarium moniliforme*, *Penicillium* species, *Nigrospora* species (*N. sphaerica* and *N. oryzae*), and *Gibberella zeae* was affected much more by differences in drying than was the second group. For instance, internal Penicillium infection was present in a significant amount only in the lots that had been dried slowly. On the other hand, *Diplodia zeae* infections were nearly constant regardless of the rate of drying. However, Diplodia infection in all these ears was very low and the results may not give a true

TABLE 3.—*Prevalence of internal seed infection in kernels of hybrid seed corn ear dried, from 30 to 12 % grain moisture, at three rates of drying, viz., four days, one month, and three months.*

Mortality and kind of seed infection	Rate of drying														
	Rapid (4 days)					Moderate (1 month)					Slow (3 months)				
	1937		1938		Average %	1937		1938		Average %	1937		1938		Average %
	Ill. 960 %	Neb. 110 %	Ill. 960 %	U.S. 13 %		Ill. 960 %	Neb. 110 %	Ill. 960 %	U.S. 13 %		Ill. 960 %	Neb. 110 %	Ill. 960 %	U.S. 13 %	
Dead kernels	0.2	1.1	0.1	0.6	0.5	0.1	3.7	0.6	0.4	1.2	2.9	2.9	9.0	4.0	4.7
Fusarium moniliforme	0.2	0.0	0.5	1.7	0.6	8.5	1.5	6.4	3.8	5.1	18.2	4.0	49.9	60.4	33.1
Penicillium spp.	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.7	0.2	25.3	18.6	15.9	2.5	15.6
Nigrospora spp.	0.4	0.4	1.6	2.3	1.2	3.9	0.8	1.7	12.0	4.6	2.0	3.2	10.2	17.8	8.3
Gibberella zeae	0.0	0.0	0.0	0.0	0.0	1.6	0.5	1.7	2.3	1.5	0.8	1.3	3.5	12.8	4.6
Cephalosporium acremonium	0.0	0.8	4.7	2.7	2.1	0.5	2.4	7.8	2.4	3.3	0.6	7.9	4.0	7.0	4.9
Diplodia zeae	0.0	0.7	0.6	0.5	0.5	0.1	1.4	1.2	0.0	0.7	0.1	0.0	1.3	1.3	0.7
Other infections	0.0	0.4	0.7	1.1	0.6	0.3	1.6	2.6	7.2	2.9	0.5	1.8	2.6	2.3	1.8
Total infection	5.1					18.3					69.0				

picture of what might happen under other seasonal conditions with greater abundance of Diplodia ear infection.

Increase in dead kernels as speed of drying decreased appeared to be caused by fungus infections. *Fusarium moniliforme*, *Penicillium* spp., and *Gibberella zeae* were the fungi most commonly associated with dead kernels in the test dishes (Fig 3, C and D).

The classification "other infections" in Table 3 includes Aspergilli, Epicocum, Helminthosporium, Hormoderndrum, and others.

FUNGUS INFECTION AND FIELD PERFORMANCE

Six ears as nearly disease-free as possible and six ears heavily infected with one disease, but all ears having 100% germination, were selected from the individual ear records. These selections were made only in the slowly dried corn because in that group the heavily diseased ears were most abundant and there were also some nearly disease-free ears. Ears showing a high percentage of kernels infected with *Penicillium* spp. were available only in one lot, but tests with *Fusarium moniliforme* seed were made with three lots (Table 4).

TABLE 4.—*Effect of disease infection in hybrid seed corn, all ears dried in chamber operated at 86% relative humidity, when planted in field tests, seed not treated with disinfectant, Urbana, Ill.*

Year	Hybrid	Seed condition	Seed infection, %	Laboratory germination, %	Field stand, %	Acre yield, bu.	Decrease because of disease infection, bu.
1938	Ill. 960	Nearly disease free	2	100	95.3	92.8	—
		Fusarium infected	53	100	93.6	88.6	4.2*
		Penicillium infected	47	100	93.8	89.0	3.8
1939	Ill. 960	Nearly diesase free	2	100	95.6	102.5	—
		Fusarium infected	73	92.5	88.7	96.9	5.6*
1939	U.S. 13	Nearly disease free	3	99.5	98.2	108.1	—
		Fusarium infected	86	99.0	90.3	98.7	9.4*

*Statistically significant decrease.

After the seed from these ears was composited and packaged for planting, similar seed was surface sterilized and tested in petri dishes on potato dextrose agar to obtain a composite test on disease infection. No seed disinfection was used on the field-planted seed.

The identity of the species of Penicillium present was not determined except that they were other than *P. oxalicium*. Had this organism been present in any considerable amount it would no doubt have had a severe adverse effect on the field performance of the plants as judged from other experiments in which this organism was present. The species present in this case caused a decrease in yield of only 3.8 bushels per acre which was not a statistically significant decrease.

Fusarium moniliforme caused a significant decrease in yield in all three of the tests. There is no doubt that strains of this fungus can

materially weaken the seedlings of corn and even kill the germ. On the other hand, it is the writers' opinion that such injuries are rare when well-processed corn that has been treated with a good disinfectant is used for planting. In the present experiments it was impossible to find six severely diseased ears in any one of the 120-ear lots that were dried rapidly. Even in the corn dried at an intermediate rate it was not possible to find six ears so severely diseased as those used in the field test reported in Table 4.

Another experiment conducted for three years, 1936–38, gives further information on the effect of *Fusarium moniliforme* seed infection. Seed of 13 different hybrids was used 200 or more ears of each being rack dried in the Agronomy Seed House similar to the method mentioned earlier in this paper. Ten ears most nearly disease-free and 10 ears with highest *F. moniliforme* infection but with 100% germination were selected from each lot. In some lots it was hard to find 10 ears that were nearly disease-free and the 10 best ears were chosen for the test even though they contained more infection than desired. In some other lots it was not possible to find 10 ears with a very high degree of *F. moniliforme* infection. A composite sample of 200 kernels of each 10-ear group was tested, without seed disinfection, on sterile muslin in a germinator, and 100 kernels of each were surface sterilized with chlorine solution and tested on potato dextrose agar in petri dishes. Comparisons of results with the two methods are given in Table 5. In the field tests, when untreated seed was used, there was an average decrease in yield of 1.8 bushels per acre from *F. moniliforme* seed infection. This decrease is small but statistically significant. When the seed was treated before planting, the difference in yield from nearly disease-free and from Fusarium-infected seed was not statistically significant.

DISCUSSION

In trying to find the reason why the corn grown from seed bin-dried by commercial hybrid seed producers yielded less on the average than that hanger-dried in the Agronomy Seed House, one difference in the seed, aside from speed of drying, was discovered. Unfortunately, most of the seed remnants left after planting had not been saved, but seven entries of the 1939 experiment, both bin- and hanger-dried, were still available when it occurred to the authors to make an examination of the kernels for seed-coat injury. In every case there was decidedly more seed-coat injury in the seed that had been bin-dried and subsequently machine processed than in the grain that had been hanger-dried and shelled by hand. Averaging the seven entries in the bin-dried corn, 3.23% of the kernels had suffered removal of one-fourth or more of the seed coat from the crown. In the hanger-dried corn, only 0.26% were similarly injured. In broken-off tip caps there also was a remarkable difference, the percentages being 2.11 and 0.14, respectively. By tip cap is meant the corky area at the end of the kernel where it is attached to the cob. In addition there were also more minor seed-coat ruptures in the bin-dried seed than in the hanger-dried. It should be recalled that the

separation of ears for hanger and bin drying was made after husking and thus the harvesting method for the two was identical.

TABLE 5.—*Effect of seed infection with Fusarium moniliforme on yield of grain in 13 corn hybrids, using untreated seed and seed treated with a good organic mercury disinfectant, Urbana, Ill.*

Hybrid	*Fusarium moniliforme* seed infection				Decrease (--) or increase (+) in yield from Fusarium infection	
	Germinator test, seed not surface sterilized		Petri dish test, seed surface sterilized			
	Nearly disease-free selections, %	Fusarium-infected selections, %	Nearly disease-free-selections, %	Fusarium-infected selections, %	Seed not treated, bu.	Seed treated, bu.
			1936			
R4×540	16.0	76.5	0.5	8.5	-1.1	-2.1
Iowa 306	17.0	76.0	0.0	4.5	-2.6	-1.3
Ill. 39	10.0	75.5	0.0	2.0	-3.2	-1.7
			1937			
Ill. 66	5.0	97.5	3.5	65.5	-0.8	0.0
Ill. 428	19.0	97.5	6.0	94.5	-4.5	-4.0
Ill. 710	6.5	86.5	1.0	54.5	+2.1	+0.1
Ill. 758	8.5	93.0	4.0	43.0	+0.3	+1.0
Ill. 762	2.5	94.0	3.0	82.0	-1.5	-4.8
			1938			
Ill. 960	3.0	72.0	0.0	64.0	-2.5	+0.3
Ill. E148	3.5	92.5	1.0	73.0	-3.6	+4.6
Ill. E133	6.0	84.0	1.0	56.0	-2.4	+0.2
Ill. 972	5.0	89.5	2.0	51.0	+0.8	+4.2
Ill. 764	9.0	94.5	4.0	52.0	-4.5	-1.3
Average	8.5	86.8	2.0	50.0	-1.8*	+0.4

*Statistically significant decrease.

In view of the fact that all the seed had been treated for seedling-disease control, the writers are not sure that the difference in seed-coat injury accounted for the differences in yield, but it is the only physical difference that could be observed. The heat used in the drying bins was ordinarily considered safe. According to statements by the producers, the temperature of the air when it entered the drying bins was not over 110° F in any case.

In field tests made from seed corn that had been dried in experimental chambers, there was no significant difference in field stand or yield of grain whether the seed had been dried from 30% moisture to 12% in four days or in one month. The differences in seed infection of 5.1 and 18.3%, respectively (Table 3), probably was immaterial because seed treatment was used, or else was counteracted by other factors. The third group which was dried very slowly showed more seed mortality and poorer field performance than either

of the first two groups. Considerable deterioration from fungi had doubtless taken place while curing and before the seed was treated and planted. Furthermore, much of the disease infection had penetrated deeply so that it probably caused trouble after planting in spite of seed treatment. Even though ears with good germination were selected for planting in these tests, the field stand from slowly dried seed suffered as compared with that from seed dried more quickly.

It is known (1)[3] that at 70° F seed stored with a moisture content of 14% ages faster and looses viability sooner than seed stored at lower moistures. Fungus growth is inhibited and does not become a factor when the moisture is 14% or lower. At higher moistures it is difficult to tell just how much damage is caused by each of the factors, aging and fungus growth. In certain experiments (4), wheat with 22% moisture stored at room temperature became moldy and germinated only 32% at the end of the test period; whereas wheat with the same moisture content and stored in the same way, except that it was treated with carbon tetrachloride vapors, germinated 92%. The vapors inhibited mold growth so that the grain retained a sound appearance. From studies of mold penetration into the corn kernels and observations of germ discolorations from disease infection in the present experiments, it is the opinion of the writers that deterioration of the slowly dried seed was due to activity of fungi to a larger extent than to physiologic aging.

The fungi mentioned by name in Table 3, except *Penicillium* spp. and possibly *Nigrospora* spp., are able to parasitize corn kernels on the immature developing ears. With *Fusarium moniliforme*, in the absence of ear worm or other mechanical damage, early infection is greatly hindered by good husk covering. Early Diplodia and Gibberella infection results in rotted ears that would not be taken for seed. Thus in these ears which were harvested in late September and selected for good husk covering and sound appearance, rapid drying held down internal seed infection to a very great extent. Under some other seasonal conditions infection in corn may be considerably higher, but the difference in internal seed infection between rapidly and slowly dried corn would no doubt still be marked. Furthermore, it is probable that in most commercial processing the ears are not selected as carefully as they were in these experiments and thus somewhat more disease infection may be expected in average commercial bin-dried seed lots than in the rapidly dried seed reported here.

With the exception of *Cephalosporium acremonium*, all of the fungi mentioned acted as storage rots under suitable moisture conditions (3), and with the additional exception of most of the Penicillia they may cause seedling diseases in the planted grain. There is danger from both of these troubles in slowly dried seed corn.

After the seed ears had been dried slowly and selections had been made for nearly disease-free ears, on the one hand, and for ears highly infected with *Fusarium moniliforme*, on the other hand, and the two kinds of seed grown in field plots, significant differences in

[3]Figures in parenthesis refer to "Literature Cited", p. 781

yield were obtained (Table 4). In other experiments with hybrid seed corn rack dried at a more rapid rate, however, the average difference in yield from nearly disease-free seed and from *F. moniliforme* infected seed was only 1.8 bushels when the seed was planted untreated (Table 5). The principal reasons for this small average difference as compared to a difference of 5.9 bushels in open-pollinated corn for a nine-year period ending in 1929 (2, p. 61) are probably three, *viz.*, (a) better resistance to injury from *F. moniliforme* in the hybrids used, (b) less difference in actual infection between the infected and nearly disease-free seed lots in the hybrids used because of less opportunity for selection of wide differences, and (c) favorable spring growing conditions during the three years in which the experiments with hybrids were conducted.

SUMMARY

Bin-dried hybrid seed corn showed no improvement in seed quality over corn hanger-dried under good conditions, as judged in field tests with seed treated for seedling disease control. In seasons when seed infection is more prevalent or when the corn matures more slowly in the fall, bin drying may probably have more value.

In field tests with representative samples of hybrid seed corn from 22 commercial seed production fields dried in two ways, namely, in hangers in the Agronomy Seed House and in drying bins operated by the seed producers, the former averaged 3.2 bushels better in yield over a three-year period. This difference was statistically significant.

Corn ears of several commercial hybrids were hand picked in seed-producing fields when the grain moisture was about 30%. The ears of each hybrid were divided at random into three lots of 120 ears each to determine the effect of different rates of drying on internal seed infection and on field performance when planted.

Chambers with temperature and humidity control were used in which the ear corn was dried down to 12% at three rates of speed, *viz.*, rapid, 106° F, requiring four days; moderate, 70° F, 65% relative humidity requiring one month; and slow, 70° F, 86% relative humidity requiring three months to reduce to 17% moisture after which it was reduced quickly to 12%.

There was no significant difference in yield between corn grown from seed dried at fast and at moderate rates. The slowly dried seed, however, produced reduced stands and yields as compared with either of the other rates of drying. This was attributed largely to fungus infection. The seed had been treated in each case for seedling disease control. The treatment proved adequate for controlling moderate infections, but when the kernels were deeply permeated with fungus mycelia, as in the slowly dried corn, good control was not obtained.

Total kernel infections after surface sterilizing the grain, averaged 5.1, 18.3, and 69.0% for fast, moderate, and slow rates of drying, respectively. The prevalence of *Fusarium moniliforme*, *Penicillium* spp., *Nigrospora* spp., and *Gibberella zeae* was increased the most by slow drying.

Field plots grown from nearly disease-free and Fusarium-infected hybrid corn kernels from ears that had been dried in an identical manner with neither kind treated with a disinfectant, showed some statistically significant reductions in yield from seed infection.

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VARIATIONS IN YIELD AND COMPOSITION OF THE WHEAT PLANT AS AFFECTED BY THE TIME OF APPLYING PHOSPHATIC FERTILIZERS[1]

CHING-KWEI LEE[2]

IT SEEMS to be definitely established that plants take up most of their phosphate supply in the early stages of growth, and it is then that the application of phosphatic fertilizers to a soil needs thorough consideration.

Gregory (3),[3] having worked with maize in sand culture, showed that the first application of phosphate was the most efficient. Later applications, although continuing to increase the rate of growth, tended to become much less effective. Gericke (2), after running a series of water culture experiments, believed that the maximum dry weight of wheat was obtainable when the plants were grown in nutrient solutions for four weeks and then transferred to solutions containing no phosphate. Brenchley (1), working with barley in water culture experiments, found that sufficient phosphate was taken up in the first six weeks to allow the plant to attain its maximum dry weight. The absence of phosphate in the early stages of growth, on the other hand, led to a rapid drop in the ultimate amount of phosphate taken up by the plant.

Owing to the presence of a minute quantity of available phosphorus in any infertile soil, the results obtained from soil cultures are generally regarded as more variable than results obtained from nutrient solutions where the supply of phosphate can be completely controlled in the early stages of growth. Knowles and Watkin (4), in a study of the assimilation of plant nutrients in wheat during growth, found that assimilation of phosphate ceased at two weeks before harvest. The experiment was conducted on a clayey calcareous soil.

The present report is an out growth of pot-culture experiments with wheat growing on a yellow earth deficient in phosphorus. Various quantities of phosphate fertilizer were added to the pots at different times. The concentration of phosphorus in the plant at different stages of growth was determined and the yield analyzed.

EXPERIMENTAL PROCEDURE

The soil selected for this experiment is known as Si-shan-ping clay loam, an old yellow earth located on a narrow horizontal depression on the top of an anticlinal ridge 80 kilos northwest of Chungking in Syzechuan Province, China. As indicated by the following analysis, this soil contains very little available phosphorus:

pH	Total P_2O_5 %	Available P, p.p.m.	Neubuaer value, P_2O_5 mg
4.5	0.08	Trace	-1.95

[1]Contribution from the National Geological Survey of China, Division of Soils, Chungking, China. Published with the consent of the Director of the Survey. Received for publication July 19, 1940.

[2]Soil Chemist. The writer is indebted to Mr. Y. C. Shang for his help in determining phosphorus in plants during the growing stages.

[3]Figures in parenthesis refer to "Literature Cited", p. 788.

3,500 grams of air-dried soil and 1,200 grams of washed sand were placed in common Mitscherlich's pots. With this were mixed in each pot 1 gram of nitrogen in the form of $Ca(NO_3)_2$ and an equal amount of K_2O in the form of K_2SO_4. Phosphate was applied later in a solution extracted from superphosphate, which had a concentration of 1 gram of P_2O_5 in 400 cc.

In each pot were sown 35 seeds which contained 0.80% P_2O_5 (dry basis). Germination proceeded uniformly after 9 days and 30 seedlings were allowed to grow in each pot. All treatments were in triplicate.

At the end of each 30 days one plant was cut from each pot for analysis. The phosphorus content was determined by Denege's colorimetric method (9) and expressed as percentage of P_2O_5 in dry matter. Available phosphorus in the soil was determined by Truog's method (8). Distilled water was used for watering the soil before the phosphate was applied, but rain water was substituted later.

RESULTS AND DISCUSSION

TIME OF APPLYING PHOSPHATE AND YIELD OF WHEAT

To ascertain the effect of time of applying phosphate on the yield of wheat, phosphate solutions containing 1.10 gram of P_2O_5 were added to one series of pots at time of sowing and to other series at intervals of 30 days. The last application was made at March 11, 120 days after sowing.

No difference in growth could be observed when the plants were 30 days old. Wheat was stunted in growth at about six weeks after sowing in pots which received no phosphate, with a brownish discoloration appearing on the tips and margins of the leaves. The brownish color gradually changed into purple and finally colored the whole leaf. Addition of phosphate at any growing stage was followed by an accelerated growth of the plants, but the response was not immediate. Improvement in growth was usually visible about 2 weeks after the application of the phosphate.

Korczewski (6), from the results of water culture experiment with maize, stated that the rate of growth at a given moment of development is determined not only by the actual P_2O_5 concentration in the external medium, but also by the concentration of phosphoric acid during the preceding days of growth. Wheat receiving phosphate 4 weeks later actually gave the same yield at harvest as wheat which received an application of phosphorus at seeding time. Applications made much later than this diminished the yield. The results are presented in Table 1.

Shortage of phosphate in the early stages of growth decreased the number of grains per ear. The time of maturity was also delayed. Ear emergence occurred by the middle of March in wheat which received phosphate at sowing (November 11) and was one week later in wheat receiving phosphorus December 11. Further delay of phosphate application successively caused slower ear emergence and late ripening as well. In fact, normal maturity did not occur in wheat which received phosphate more than 90 days after sowing, the plants remaining greenish in color in both straw and ears until they died. The recovery of phosphate by the tops of plants which received phosphate at sowing was 25.2%. This figure included the phosphorus

originally contained in the seeds. Later application of phosphate caused successively lower recovery.

TABLE 1.—*Yield of wheat in relation to time of applying phosphate.*

	Time of application of 1.10 grams P_2O_5, days after sowing					
	0 Nov. 11	30 Dec. 11	60 Jan. 11	90 Feb. 11	120 Mar. 11	Check, no addition
Weight ears, grams.	28.98	27.87	23.70	11.31	3.10	0.75
Weight straw, grams	40.02	40.38	24.50	11.90	4.65	1.63
Total, grams	69.00	68.25	48.20	23.21	7.75	2.38
P_2O_5 in ears, mg	225.2	209.0	177.5	62.4	18.5	3.3
P_2O_5 in straw, mg	52.2	56 2	49.3	50.2	30.1	1 5
Total, mg	277.4	265.2	226 8	112.6	48.6	4.8
P_2O_5 recovered, %	25.2	24.1	20.5	10.2	4.4	—
Average height, cm	121	121	91	75	41	20
No. grains per ear	34	33	27	16	10	6

Examination of the concentrations of phosphorus in the plants 30 days after sowing showed that plants which received phosphate at sowing contained 0.93% of P_2O_5 in the dry matter, while those which received no phosphate contained 0.51–0.55%. Successive determinations of phosphorus in the former case showed that the concentration of P_2O_5 decreased gradually as growth proceeded and declined to a rather steady value of about 0.50% (Table 2).

According to Korczewski (6), the intensity of growth processes which are going on in the plant does not depend directly upon the phosphate concentration outside the plant but upon the amount of phosphoric acid available in cells and growing tissues. Thus, at the earliest stage of growth wheat grows merely at the cost of the accumulated P_2O_5 in the seed. After about 30 days, when the plants have grown bigger and the content of P_2O_5 per unit of dry weight is rapidly diminishing, the direct supply of phosphoric acid by absorption becomes the limiting factor.

As shown in Table 2, when the concentration of P_2O_5 in wheat dropped to 0.51–0.55%, stunting of growth commenced. Further growth of the plant without a supply of available phosphorus from the soil caused successive diminution of phosphate in the plant cells and a purplish discoloration of the leaves characteristic of phosphate deficiency. Addition of phosphate at any stage of growth was accompanied by a marked increase of P_2O_5 in the plant tissues to about 0.90–0.97% and the plant recovered normal growth.

At the end stage of growth, transference of phosphate to the grain is very distinct. The concentration of P_2O_5 in the ears was nearly six times that in the straw. This process, according to Knowles and Watkin (4), proceeded until within about a week before harvest. In their detailed study of the amounts and distribution of phosphorus compounds in wheat during growth (5), they also found that at

harvest three-fourths of the phytin, four-fifths of lipin, and the whole of the inorganic phosphorus was in the ear. In wheat receiving phosphate more than 90 days after sowing and in which the ripening process was not completed, a greater part of the phosphoric acid was retained in the straw.

TABLE 2.—*Concentrations of phosphoric acid in wheat plants which received phosphate at different stages of growth.*

Time of applying 1.10 grams P_2O_5	Percentage P_2O_5 in dry tissue at growing periods, days after sowing					Percentage P_2O_5 at maturity	
	30 Dec. 11	60 Jan. 11	90 Feb. 11	120 Mar. 11	150 Apr. 11	Ears	Straw
Nov. 11, at sowing	0.93	0.83	0.57	0.48	0.46	0.77	0.13
Dec. 11	0.51	0.91	0.77	0.57	0.46	0.75	0.14
Jan. 11	0.55	0.22	0.93	0.83	0.62	0.75	0.20
Feb. 11	0.51	0 20	0.15	0.97	0.75	0.55	0.42
Mar. 11	0.53	0 20	0.16	0.13	0.90	0.60	0.65
No addition	0.51	0 21	0.18	0.17	0.17	0.44	0.09

RATE OF APPLICATION OF PHOSPHATIC FERTILIZER AND YIELD RESPONSE

Si-san-ping clay loam is an old yellow earth containing very little phosphate. P_2O_5 to the amount of 0.1100, 0.2750, 0.5500, 0.8350, 1 1000, and 2.000 grams was added at seeding time. The available phosphorus markedly increased with the increased amount of phosphate solution applied per pot (Table 4). The results differed from the plot experiment of Richer and White (7) where the addition of double or triple amounts of superphosphate showed only small increases in available phosphorus extract.

Almost no yield was obtained where no phosphate was added. Maximum yields seemed to have been obtained when 1.1 grams of P_2O_5 were added per pot. An excess of phosphate, although causing no decrease of yield, showed a diminished return. A higher percentage recovery of P_2O_5 was not found in cases which gave maximum yields. Small doses of P_2O_5 also resulted in little recovery. This was affected by the fixation of phosphate in the strongly acid soil. The results are presented in Table 3.

Deficiency in phosphate delayed maturity. In the pots containing only a trace of available phosphorus, the ripening process was not completed, the ears and straw retaining a greenish color. High concentration of available phosphorus in soils did not effect an abnormal increase of phosphorus concentration in plant cells. Wheat seemed to keep a maximum inside concentration of P_2O_5 at about 0.95% in its earliest stage of growth (Table 4). A lower concentration of P_2O_5 at that time limited the growth in subsequent periods. Transference of phosphate to the grain was also very distinct in wheat suffering from phosphate starvation. The straw retained little phosphorus, while a large portion was accumulated in the grain. Where normal

TABLE 3.—*Rate of application of phosphatic fertilizer and response of yield of wheat.*

	Weight of P_2O_5 added per pot, grams						
	2.0000	1.1000	0.8250	0.5500	0.2750	0.1100	No addition
Weight ears, grams	30.03	28.98	26.55	21.34	6.87	1.53	0.75
Weight straw, grams	40.18	40.02	29.80	26.25	14.84	4.22	1.63
Total, grams	70.21	69.00	56.35	47.59	21.71	5.75	2.38
P_2O_5 in ears, mg	231.0	225.2	193.0	149.9	39.2	9.0	3.3
P_2O_5 in straw, mg	54.4	52.2	35.8	34.6	16.2	5.5	1.5
Total, mg	285.4	277.4	228.8	184.5	55.4	14.5	4.8
P_2O_5 recovery, %	14.3	25.2	27.8	33.5	20.1	13.2	—
Average height, cm	121	121	116	104	75	26	20
No. grains per ear	34	34	22	20	17	6	6

growth was attained, wheat also preserved a definite percentage of P_2O_5 at maturity, i.e., about 0.75% in the ear and 0.13% in the straw. An ample supply of available phosphorus in the soil did not increase these values, but in soils deficient in phosphate these figures declined.

TABLE 4.—*Concentration of phosphoric acid in wheat receiving different amounts of phosphate*

P_2O_5 added per pot, grams	Available P, p.p.m.	Percentage P_2O_5 at different times, days after sowing					Percentage P_2O_5 at maturity	
		30 Dec. 11	60 Jan. 11	90 Feb. 11	120 Mar. 11	150 Apr. 11	Ears	Straw
2.0000....	202	0.95	0.88	0.64	0.55	0.48	0.77	0.13
1.1000....	80	0.93	0.83	0.57	0.48	0.46	0.78	0.13
0.8250.....	52	0.93	0.75	0.56	0.38	0.37	0.73	0.12
0.5500.....	30	0.77	0.66	0.51	0.40	0.37	0.72	0.13
0.2750.....	22	0.62	0.53	0.31	0.26	0.25	0.58	0.11
0.1100...	Trace	0.56	0.39	0.38	0.22	0.21	0.59	0.13
No addition	Trace	0.53	0.21	0.18	0.17	0.17	0.44	0.09

TIME OF APPLYING PHOSPHATE TO SOILS OF DIFFERENT DEGREES OF PHOSPHATE DEFICIENCY AND YIELD OF WHEAT

An additional series of experiments was conducted in which 0.11, 0.275, to 0.550 gram of P_2O_5 were applied at seeding time. A supplementary quantity of P_2O_5, making the total application 1.10 grams per pot, was added at different stages of growth. The plants thus received an equal amount of P_2O_5 but were subjected to different degrees of phosphate deficiency at early stages of growth. The results are presented in Table 5.

TABLE 5.— *Yield of wheat and time of applying phosphate to soils of different degrees of phosphorus deficiency.**

Dates when additional P_2O_5 was added	Weight ears, grams	Weight straw, grams	Total, grams	P_2O_5 in ears, mg	P_2O_5 in straw, mg	Total, mg
0.11 gram P_2O_5 Added Per Pot Before Sowing, Available P Trace, 0.99 gram P_2O_5 Added						
Dec. 11	27.28	38.75	66.03	216.9	75.5	292.4
Jan. 11 . .	23.49	26.28	49 77	178.3	65.8	244.1
Feb. 11 . .	11.44	14.45	25.89	70.0	59.8	129.8
No addition.	1.53	4.22	5.75	9.0	5.5	14.5
0.2750 gram P_2O_5 Added Per Pot Before Sowing, Available P 22 p.p.m., 0.8250 gram P_2O_5 Added						
Dec. 11 .	28.77	39.80	68.57	209.3	81.2	290.5
Jan. 11 . . .	27.00	36.41	63.41	208.2	73.2	281.4
Feb. 11 .	19.17	24.32	43.49	140 0	71.8	211.8
No addition	6.87	14.84	21.71	39.2	16.2	55.4
0.55 gram P_2O_5 Added Per Pot Before Sowing, Available P 30 p p.m., 0.55 gram P_2O_5 Added						
Dec. 11	29 34	41.35	70 69	229.7	80.1	309.8
Jan. 11 . .	30 94	40 13	71.07	224 4	80.4	304.8
Feb. 11	27.01	37.45	64.46	195.4	82.4	277.8
No addition	21.34	26.25	47 59	149.9	34.6	184.5

*Wheat sown on November 11.

The presence of a small quantity of available phosphorus in soils increased the efficiency of phosphatic fertilizers applied later. In Table 1 it is shown that where 1.10 grams of P_2O_5 were added 90 days after sowing, the total yield was 23.21 grams. When one-fourth of the phosphate was added before sowing, the yield was nearly doubled, revealing the harmful effect of phosphate starvation in the early stages of growth. A severe shortage of phosphate caused an abnormal decrease of phosphorus concentration in the plant cells and consequently injured them. In soils where there was not a serious deficiency of phosphorus, the decrease in efficiency of later applications of phosphate was less marked.

SUMMARY

Yellow earth, a soil of serious phosphate deficiency, was used in this trial. Pot-culture experiments on the effect of applying a phosphatic fertilizer to wheat gave the following results:

1. Applications of phosphate 30 days after sowing gave the same yield as when the application was made at seeding time.
2. Later applications of phosphate successively caused lower efficiency. The times of ear emergence and ripening were delayed.
3. The concentration of P_2O_5 in wheat tissue was suddenly increased to about 0.95% after each addition of phosphate. A large excess of phosphate present in the soil did not increase the concentration of phosphoric acid in plants above this figure.

4. Where the phosphate was applied at later stages of growth, more phosphoric acid was retained in the straw.

5. A deficiency of available phosphorus in the soil, not only reduced the yield of wheat, but also diminished the concentration of phosphoric acid in the plant cells.

6. The presence of a small amount of available phosphorus in the soil made later applications of phosphatic fertilizer much more efficient.

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EFFECT OF DIFFERENT LIME LEVELS ON THE GROWTH AND COMPOSITION OF SOME LEGUMES[1]

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GROWING of legumes for soil building, for pasture, and for hay is a well-established practice and any economic means of increasing the amount and quality of these crops is desirable. Not only has the acreage devoted to legumes in the South been greatly increased in the past few years, but also the problems associated with their culture. Although the importance of sufficient calcium has long been recognized, there are undoubtedly other fertility factors to which leguminous crops are sensitive in southern soils. The response to different soil conditions in the South show wide variation not only among the different legumes, but also with the same legume grown on different soils. Since it has been shown by Albrecht (3)[3] that with soybeans the detrimental effect of soil acidity was brought about not so much by the degree of acidity as by the deficiency of available calcium in the soil, considerable attention has been directed toward the determination of the effect of degree of base saturation on the growth of legumes.

Albrecht and Smith (2) have also reported greenhouse work from which they concluded that in liming and fertilizing the soil, attention must go to the degree of saturation of the soil. Davis and Brewer (4) have shown that application of lime and superphosphate to soils low in calcium content enabled the plant to absorb larger quantities of calcium, phosphorus, and nitrogen. Horner (5) has reported that by raising the base saturation of a soil colloid from 40% to 97%, the total amount of calcium taken up by the crop was more than doubled. In order to determine whether calcium is an important factor in the success or failure of legumes on certain soils of Mississippi, greenhouse and laboratory investigations were conducted on Grenada silt loam soil, using soybeans, Korean lespedeza, and sweet clover as indicator crops.

PROCEDURE

Some of the surface soil of Grenada silt loam, which is a soil developed from Loessial material, was taken from a cultivated field and brought to the greenhouse and prepared for various treatments. The titratible hydrogen was determined by titrating a 10-gram sample (dry weight) with 0.04 N calcium hydroxide from the initial pH, which was 4.7, to 7, using the glass electrode. The treatments consisted of adding re-precipitated calcium carbonate in the amounts necessary to neutralize 25, 50, 75, and 100% of the titratible hydrogen, respectively. For each kilogram of this soil, it took 8, 16, 24, and 32 M.E. of calcium to neutralize 25, 50, 75, and 100% of the titratible hydrogen, respectively. All treatments received a uniform application of 0–8–6 fertilizer at the rate of 500 pounds per acre.

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[3]Figures in parenthesis refer to "Literature Cited", p. 793.

After the addition of lime and fertilizer, a weighed quantity of the mixture was placed in small pots and pans and arranged so that each treatment was replicated four times, including a check series. The moisture content was raised to approximately 20% of the water-holding capacity of the soil and maintained at that level as closely as possible throughout the experiment. A pH determination was made on the soil of each treatment prior to seeding. The five treatments, which included a check, were seeded to soybeans, Korean lespedeza, and sweet clover. The seeding was done in February and the plants were harvested at bloom stage which was the first of May. The above-ground portion of the plants grown on each series was harvested and weighed to obtain yields, and samples of the plant materials were collected and analyzed for calcium, nitrogen, and phosphorus according to the A. O. A. C. methods.

EXPERIMENTAL RESULTS AND DISCUSSION

That calcium does have a decided effect on the growth and composition of legumes is shown in Table 1 and in Figs. 1, 2, and 3. This effect, however, is not the same for all legumes. The yield of soybeans, for example, was only increased from 21.5 grams to 25.5 grams by the addition of calcium carbonate sufficient to neutralize all of the titratible hydrogen; whereas, the yields of lespedeza and sweet clover were increased from 7.4 grams to 21.4 grams and from 8.0 grams to 19.3 grams, respectively, when the same amounts of calcium carbonate were added. These increases expressed on a percentage bases would be approximately 20, 200, and 140% for soybeans, lespedeza, and sweet clover, respectively. Although the lespedeza is usually considered to

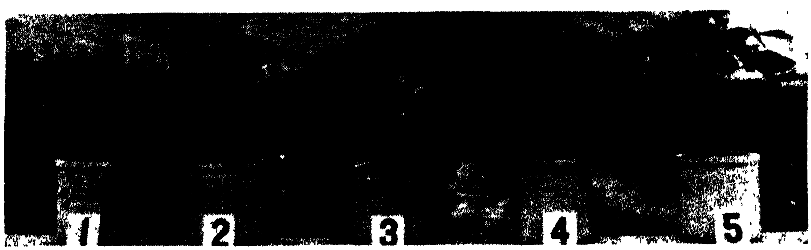

FIG. 1.—Influence of lime on the growth of soybeans. Increasing Ca from left to right: (1) Check; (2) 25% of the titratible hydrogen neutralized; (3) 50% of the titratible hydrogen neutralized; (4) 75% of the titratible hydrogen neutralized; (5) 100% of the titratible hydrogen neutralized.

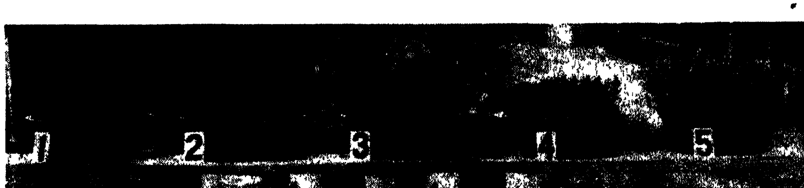

FIG. 2.—Influence of lime on the growth of Korean lespedeza. Increasing Ca from left to right: (1) Check; (2) 25% of the titratible hydrogen neutralized; (3) 50% of the titratible hydrogen neutralized; (4) 75% of the titratible hydrogen neutralized; (5) 100% of the titratible hydrogen neutralized.

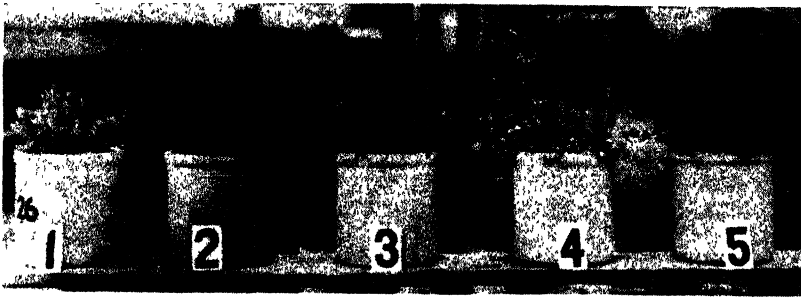

FIG. 3.—Influence of lime on sweet clover. Increasing Ca from left to right: (1) Check; (2) 25% of the titratible hydrogen neutralized; (3) 50% of the titratible hydrogen neutralized; (4) 75% of the titratible hydrogen neutralized; (5) 100% of the titratible hydrogen neutralized.

be an acid-tolerant plant, in this experiment it showed the greatest response to additions of calcium carbonate of any of the legumes tested. On the other hand, sweet clover is usually considered to be very sensitive to a deficiency of calcium in the soil, but in this trial it did not respond as well as lespedeza to additions of calcium carbonate.

TABLE 1.—*The influence of calcium on the yield and composition of soybeans, lespedeza, and sweet clover.**

Pot No.	Treatment per kg of soil	pH	Yield, grams	Plant material: Percentage			Plant material: Total removed by plants, grams		
				Ca	N	P	Ca	N	P
				Soybeans					
1	Check (no Ca)	4.7	21.5	0.100	1.74	0.162	0.022	0.374	0.035
2	8 M. E of Ca	5.1	21.9	0.110	1.85	0.145	0.024	0.405	0.031
3	16 M. E. of Ca	6.1	22.4	0.114	2.01	0.117	0.026	0.450	0.026
4	24 M. E. of Ca	6.5	23.0	0.124	2.01	0.119	0.029	0.462	0.027
5	32 M. E. of Ca	7.0	25.5	0.130	1.94	0.114	0.033	0.495	0.029
				Korean Lespedeza†					
1	Check (no Ca)	4.7	7.4	0.071	2.20	0.103	0.005	0.163	0.008
2	8 M. E. of Ca	5.1	9.6	0.099	2.28	0.159	0.010	0.219	0.015
3	16 M. E. of Ca	6.1	13.0	0.104	2.27	0.145	0.014	0.295	0.019
4	24 M. E. of Ca	6.5	14.4	0.112	2.31	0.155	0.016	0.333	0.022
5	32 M. E. of Ca	7.0	21.4	0.133	2.35	0.229	0.029	0.503	0.049
				Sweet Clover					
1	Check (no Ca)	4.7	8.0	0.128	2.41	0.312	0.010	0.193	0.025
2	8 M. E. of Ca	5.1	10.9	0.136	2.69	0.260	0.015	0.293	0.028
3	16 M. E. of Ca	6.1	13.9	0.132	2.75	0.221	0.018	0.382	0.031
4	24 M. E. of Ca	6.5	14.1	0.137	2.71	0.190	0.019	0.382	0.027
5	32 M. E. of Ca	7.0	19.3	0.136	2.46	0.179	0.026	0.475	0.025

*Yields and percentages based on oven-dry weight.
†The Lespedeza was grown only in two replications.

The total amount of calcium removed by all three legumes increased consistently with each addition of calcium carbonate. The total amount of calcium removed by the soybeans varied from 0.022 gram for the check to 0.033 gram for the series to which sufficient calcium was added to neutralize all of the titratible hydrogen, while the amounts removed by the lespedeza and sweet clover varied from 0.005 gram to 0.029 gram and from 0.010 gram to 0.026 gram, respectively. These represent an increase in the amount of calcium absorbed of approximately 50, 480, and 160% for soybeans, lespedeza, and sweet clover, respectively. The lespedeza was, therefore, more efficient in the absorption of calcium than the other two legumes.

The percentage of nitrogen of the plant material did not fluctuate greatly in any case with each addition of calcium carbonate, but the fluctations were less above pH 6 than below pH 6. The total amount of nitrogen removed increased with each added increment of calcium carbonate which would raise the protein content of the hay crop. The most consistent increase was obtained from the plant material of the lespedeza. Calcium seemed to stimulate the fixation of nitrogen very definitely until 50% of the titratible hydrogen was neutralized.

In the case of soybeans and sweet clover, the phosphorus content decreased with each addition of calcium carbonate and the total amount removed by the plants was also less in some cases. The phosphorus content of the lespedeza did not increase consistently with each added increment of calcium carbonate, but the total amount removed by the plants increased definitely. This increase of absorbed phosphorus agrees very favorably with some recent data obtained by Albrecht and Klemme (1) with the same crop. The total amount of phosphorus removed by the lespedeza increased from 0.008 gram for the check series to 0.049 gram for the series that had 100% of the titratible hydrogen neutralized with calcium carbonate. This represents an increase of approximately 512% above the check for the series receiving the maximum amount of calcium carbonate. From the above data, it is obvious that an increase in mineral content as well as yield may be expected from liming Korean lespedeza, even though it is usually considered an acid-tolerant plant. Lespedeza showed more consistent increases in yield, calcium, nitrogen, and phosphorus contents than any plant used in this investigation.

SUMMARY

Some Grenada silt loam which was low in exchangeable bases was treated with calcium carbonate so that 25, 50, 75, and 100% of the titratible hydrogen was neutralized. Soybeans, Korean lespedeza, and sweet clover were grown on the soil which was treated with calcium carbonate in order to obtain five base levels, including a check series for each crop.

The yields of soybeans, lespedeza, and sweet clover increased with increasing additions of calcium carbonate, but the increase was not of a uniform magnitude for each of the three legumes.

The calcium content and the total amount removed by the plants increased with each increasing increment of calcium in all the crops grown.

The percentage of nitrogen did not fluctuate greatly in any case, but the variations were greater below pH 6 than above pH 6. The total nitrogen removed by the lespedeza and soybeans increased with each addition of calcium carbonate.

The phosphorus content and the total amounts removed by the soybeans and sweet clover decreased with increasing increments of calcium carbonate. The total amount removed by the lespedeza increased with each addition of calcium carbonate.

Korean lespedeza gave greater responses to applications of calcium and seemed to be more efficient in the absorption of nutrients than soybeans and sweet clover.

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THRESHING AND CLEANING EQUIPMENT FOR SUGAR BEET SEED[1]

H. W. BOCKSTAHLER AND RALPH F. SEAMANS[2]

A NUMBER of seed-harvesting and seed-cleaning problems have arisen in connection with sugar beet breeding investigations of the Division of Sugar Plant Investigations which have led to devising at Rocky Ford, Colo., by the writers special machines to do the work efficiently. In leaf-spot-resistance breeding, inbred strains are produced, necessitating threshing and cleaning of seed from isolated plants or from bagged branches of plants grown in a seed plot. In other cases, group increases, consisting of a few to several hundred plants, are made. Where the quantity of material is not bulky, the seed stalks have been gathered in burlap bags, left to dry, and then threshing and cleaning operations are conducted in the seed house. On the other hand, to produce elite seed, seed plots varying in size from about 1/100 acre to an acre or more are grown. In such cases, the seed stalks are commonly shocked in the field and threshed from the shock. In crossing inbred stains to produce F_1's for test of combinations of inbreds, rows of one inbred are commonly grown adjacent to rows of another inbred. This seed is harvested according to mother strain, shocked to cure, and then threshed. In this breeding work, seed quantities may range from less than an ounce to several pounds and, with large increases, may reach 1,000 pounds. In all operations, due precautions must be taken against any contamination of seed lots.

The machines that have been devised for the various types of seed increases are as follows: (1) Combination thresher and draper for individual plants or small groups of plants, (2) suction seed separator for removal of light, non-viable seed balls, (3) a sugar beet seed polisher to remove corky ridges from seed balls and crush many of the empty seed balls, and (4) a combination thresher and suction seed separator (Fig. 1).

In some of these machines, apparently new principles have been employed. The details of operation are briefly stated and, as necessary, drawings to scale are given. It is probable that, by appropriate adaptations, some of the machines may be useful for other crop plants.

COMBINATION THRESHER AND DRAPER

This machine was devised to thresh and clean, at one handling, plants from which seed yields of an ounce or less, up to several pounds were obtained. To avoid any admixture from previous seed lots run through the machine, attempt was made to have the machine as

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[2]Junior Pathologist and Agent, respectively. The writers wish to acknowledge their indebtedness to G. H. Coons, Principal Pathologist, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, and to A. W. Skuderna, Manager, Beet Seed Operations, American Crystal Sugar Company, for advice and assistance in the preparation of the manuscript.

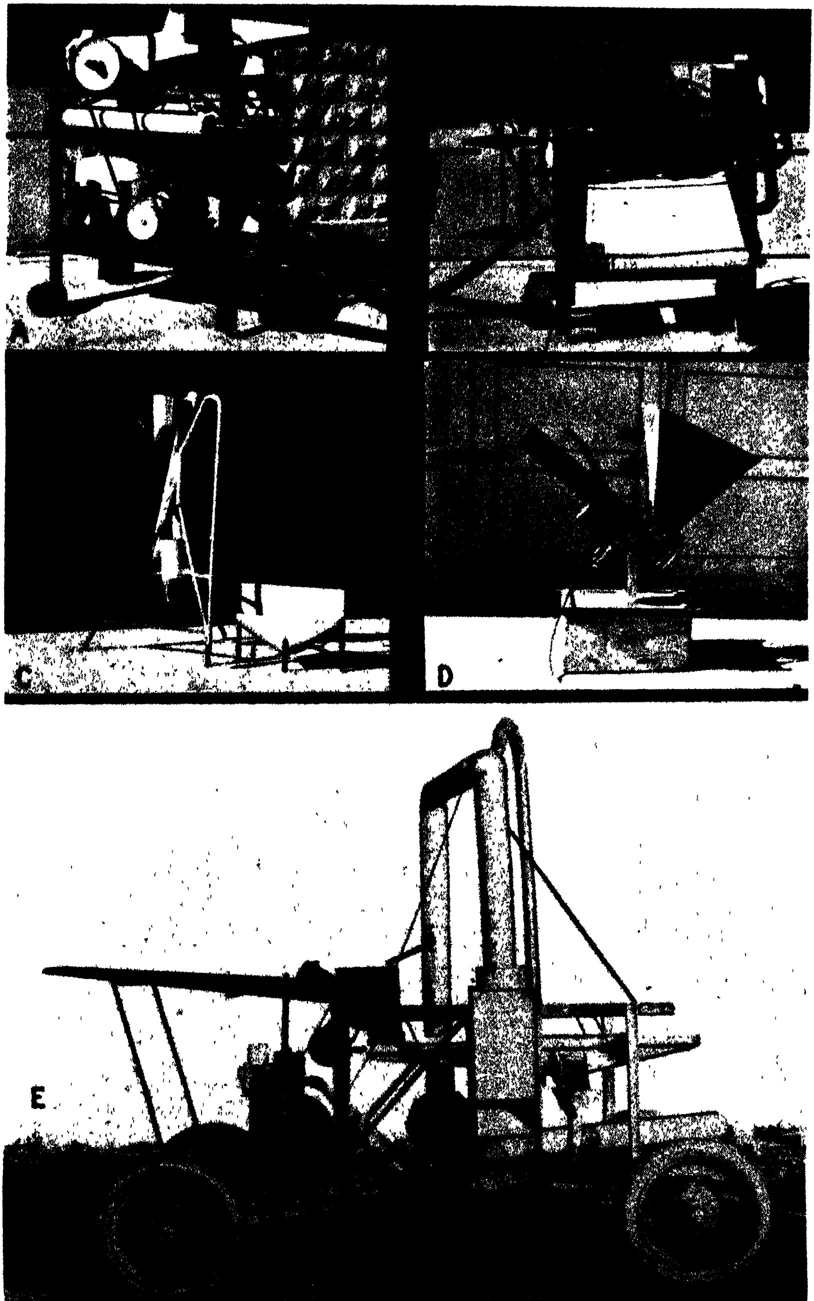

FIG. 1.—Threshing and seed cleaning equipment for sugar beet seed. A and B, front and side views of combination thresher and draper for small samples;

nearly self cleaning as possible by sloping or banking off any portions of the frame or operating parts in which seed might lodge. The threshing is accomplished by a saw-toothed cylinder which revolves close to the thresher plate or concave at about 1,200 R.P.M. The cylinder is composed of a number of coarse-toothed circular cross-cut saws 8 inches in diameter, placed along a mandrel. It was found more economical to use saws stamped from 10-gauge black iron than steel saws. The more malleable material had the additional advantage of being less subject to breakage of saw teeth if hard objects, such as stones or thick stems, were encountered.

The saws are spaced about 3/8 inch apart by composition washers 6½ inches in diameter. The saws and washers are arranged on the mandrel shaft at a 5- to 7½- degree angle from perpendicular, in order to produce a weaving motion of the saws across the concave as the cylinder revolves. Suitably beveled end plates, equipped with a lock nut, clamp into place the saws and spacers, tilted as indicated.

The thresher plate or concave is a curved, metal plate, shaped to conform to the saws and slightly longer than the cylinder. Its width is about 1/6 of the circumference of the cylinder. Two 1/8-inch round metal rods are welded horizontally on the threshing plate to form ridges which function to prevent seed stalks from sliding through before being thoroughly threshed. The saw teeth operate about 1/16 inch from these ridges. The cylinder and concave are enclosed in a black-iron housing so constructed that the top shield may be tipped back on a hinge to facilitate inspection of the drum and the concave. A metal baffle, 2 inches high, extending the length of the cylinder, is riveted on the shield to prevent the revolving cylinder from blowing back dust and fine trash.

The seed stalks to be threshed are fed slowly from the platform into the housing where the cylinder and concave thresh the seed from the stalks. The threshed material, after passing between the cylinder and concave, drops to a coarse mesh shaking screen. Suction from a small fan in the cylinder housing carries dust and fine material into a suitable dust collector. Coarse stems are carried off at the discharge end of the shaker; the seed and fine stems pass through the screen.

Separation of the seed from the fine stems is accomplished by a sloping canvas draper which is placed to operate just below the screen. The draper consists essentially of a 30-inch endless canvas belt which is drawn tightly over a pair of octagonal rollers. Rollers of this shape tend to agitate the canvas belt as it revolves, thus preventing lodgment of seed among the stem fragments. As power is applied by means of a pulley on the upper roller, the canvas belt moves upward. Seed balls bounce or roll into a collecting trough, the stems and trash being carried over the top of the canvas belt. In the present machine, side pieces of the frame are equipped with canvas guards or flaps to prevent seed from finding lodgment in corners or angles of the frame.

This machine has been found to reduce greatly the time required for cleaning small seed lots. The seed as it comes from the draper is free from dust and stems. Further removal of small seeds by sieves, or other means, can readily be accomplished.

SUCTION SEED SEPARATOR

Separation of light, chiefly non-viable, sugar beet seed balls has presented a very difficult problem, almost impossible of efficient accomplishment with larger quantities of seed. An apparatus utilizing an up-draft of air to elevate the seed and to winnow light seed from the heavier, viable component has been devised, and this has been found to work very effectively. The principle can be adapted to similar problems with other seeds or other materials.

The principle of separation is based on the fact that viable seed balls are heavier per unit of volume than non-viable seed balls, and when a sample is discharged into a separation chamber in which the up-draft of a given strength is maintained, the lighter portion is carried upward to a hopper and the heavier seed drops. In operation, it is necessary that gradations of up-draft be obtainable, in order that from sample to sample the proportions removed as "light" seed may be suitably varied. In operation, sugar beet seed is first elevated from the intake hopper on the floor, or other convenient level, into the feed pipe by means of the suction from a vacuum sweeper fan. The seed is then introduced into the separation chamber about half way down from the top of the chamber by means of a tapering conductor which connects, at an angle of approximately 45°, the feed pipe and the separation chamber. The separation chamber is a verticle pipe approximately twice the diameter of the feed pipe.

The up-draft in the separation chamber is variable, its strength being increased or reduced by different settings of air intake openings. Fig. 2 shows the details of the apparatus. The seed hoppers of the apparatus are shaped so as to be self-cleaning and are equipped with close-fitting doors which, with smaller samples, hold the seed in the hoppers until the suction fan is shut off. It is essential that the upper seed hopper have a baffle plate to deflect the light seed from the suction fan.

When a sample of seed is to be cleaned, some estimate of the percentage of seed balls with unfilled locules is obtained by cracking a sample. The apparatus is then given a preliminary setting and the sample run through. Repeated runs can be made, increasing or decreasing the up-draft to secure the type of separation desired.

Some results of sugar beet seed separation are given as illustrative of what the apparatus will do. A seed lot germinating 86% and producing 158 sprouts per 100 seed balls was put through the suction separator. The lighter portion germinated 59% with 68 sprouts per 100 seed balls and the heavier portion 92% with 187 sprouts per 100 seed balls. Of greater interest, however, are the separations possible with seed lots so low in germination as to be practically unusable for planting with the drill. A seed lot germinating 33% and producing 56.5 sprouts per 100 seed balls was separated into two portions. The lighter portion germinated only 2%, with 2 sprouts per 100 seed balls; and the heavier portion, 53%, with 84 sprouts per 100 seed balls. Successive re-separations could have been given this seed lot to raise the germination percentage, but such additional handlings probably would have involved some loss of viable seed by carry-over with the lighter portions.

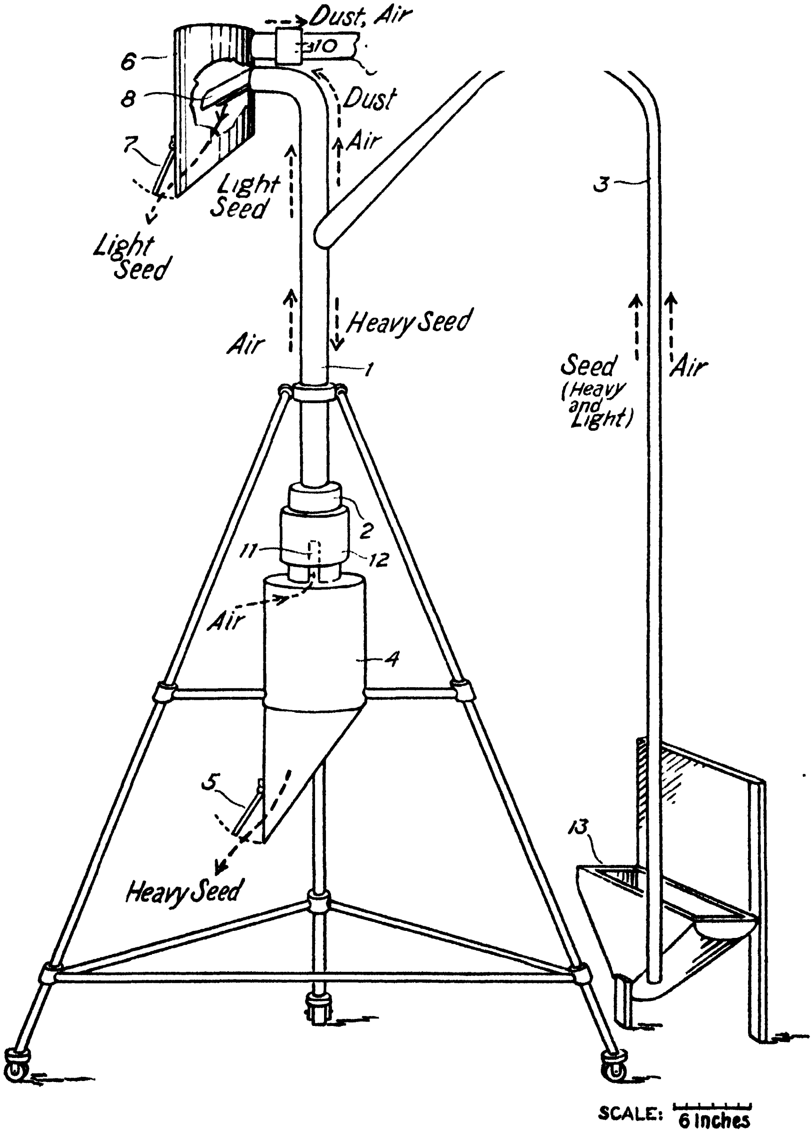

FIG. 2.—Detail drawing of the suction seed separator. Up-draft from a vacuum sweeper fan connected to the upper part (9) is subject to primary regulation by the sleeve-covered slot (10). This draft elevates seed to be separated in the intake pipe (3), carrying it to the separation chamber (1). The light seed is carried to the upper hopper (6), a baffle deflecting it from being drawn into the fan. The sleeve (12) covering the lower slot (11) gives additional regulation of the draft in the separation chamber. The lower seed hopper for heavy seed (4), as well as the upper hopper, are equipped with close-fitting swing doors which remain closed with small quantities of seed until the suction fan is shut off. The small metal seed bin (13) has sloping sides and stands at such height that all seed dumped into it is elevated when suction is applied.

Something of the weight differentials encountered in sugar beet seed balls is shown by the following data obtained after polishing and suction separating a sample of low germinating seed. The average weight of 100 seed balls of the seed as it came from the draper was 1.335 grams. After polishing, the seed was separated into light and heavy fractions. One hundred seed balls of the light fraction weighed, as an average, 0.83 gram; while 100 seed balls from the polished, heavy fraction averaged 1.94 grams. The light fraction was then re-polished and re-separated. One hundred seed balls of the light fraction obtained by re-separation weighed 0.612 gram, and 100 seed balls from the heavy fraction after re-separation 1.310 grams. The relative proportions of seed obtained after these handlings were noted. The first polishing and separating divided the sample into two fractions, approximately equal in weight. The light seed after re-polishing and re-separation was, with one setting of the up-draft, divided 74% light seed balls, 26% heavy; while with another run, with slightly different setting as to draft, the separation was 63% light, and 37% heavy.

SUGAR BEET SEED POLISHER

This machine was devised to remove excess corky tissue from the seed balls and to crush light, empty seed balls. By removing excess cork from the seed balls, separation of the light, barren seed from the heavy seed can be more readily accomplished by means of the suction seed separator.

The polisher (Fig. 3) consists essentially of a helicoid feed mechanism to advance the seed from the hopper into a cylindrical chamber. A rotating shaft which is studded with short, steel pegs runs the length of the cylindrical chamber. The function of this studded shaft is to stir the seed and advance it through the cylinder. The pegs move with enough clearance so that seed does not wedge between them and the wall. As the shaft rotates, the seed balls within the chamber are ground against each other. After traveling the full length of the cylinder, the polished seed balls spill out at the end. The rate of movement of the seed through the cylinder is determined by the angle of elevation of the cylinder. A simple ratchet device serves to set the machine in the desired position.

In changing from one seed lot to another, the seed chamber can be completely cleaned by lowering the discharge end and allowing the machine to run empty for a brief period. The machine is a separate unit and operates equally well with relatively small quantities of seed or with continuous flow of seed from the hopper. The seed must travel the full length of the cylinder before being discharged, thus giving uniformity of treatment.

Results obtained with two seed lots are given below as examples of the improvement obtainable by polishing treatment and from combining this treatment with subsequent suction seed separations. The figures in parentheses denote the germination percentages found for the samples.

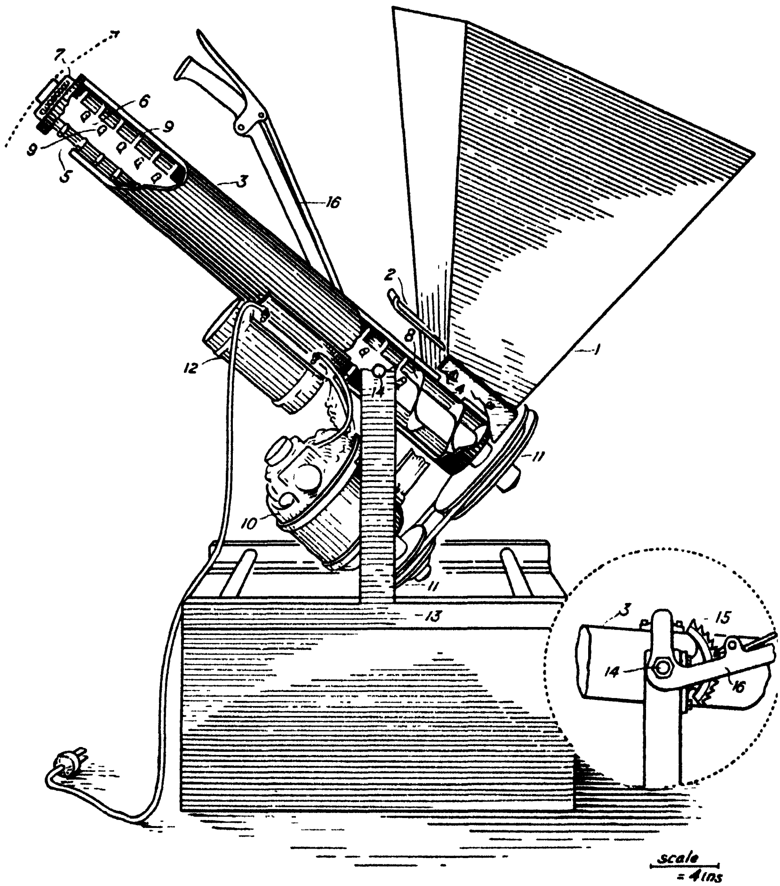

FIG. 3.—Detail drawing of the sugar beet seed polisher. Seed to be polished is dumped into the hopper (1). The helicoid feed (4) on the rotating shaft (8) forces the seed along into the chamber (3). The steel pegs (9) operate close to the cylinder wall and serve to stir the seed. The grinding of the seed balls against each other removes the corky ridge and crushes most of the empty seed balls. The polished seed and the debris spill out at the exit port (5) The shaft bearings (7), frame (13), pulleys (11), motor, etc., are shown. The inset gives the detail of the ratchet device for changing the angle of elevation of the seed chamber which governs degree of polishing given.

Seed Lot A

Original (33%): Suction-separated into light (2%) and heavy (53%).

Original (33%): Polished, suction-separated into light (16.5%) and heavy (56%).

Light seed (16.5%): Polished, suction-separated into light (7%) and heavy (30%).

Seed Lot B*

Original (30%): Polished, then suction-separated into light (20%) and heavy (74%).

Light seed (above) (20%): Re-polished, re-separated into light (12%) and heavy (62%).

*In this series, seed balls were soaked a few hours in running water prior to putting on blotters to germinate.

COMBINATION THRESHER AND SUCTION SEED SEPARATOR

To provide a thresher and cleaner which could be used with relatively large-sized seed plots, a machine was built in which the suction seed separator was made a part of the field threshing outfit (Fig. 4). The threshing outfit consisted of a 12-inch saw cylinder and concave, as previously described, and a shaking screen. The larger stems and trash were discharged from the screen, the sugar beet seed and small stems passing through. A gathering pan, placed beneath the screen, was so shaped as to direct the flow of screened material to the intake hopper of the suction seed separator. The entire equipment was

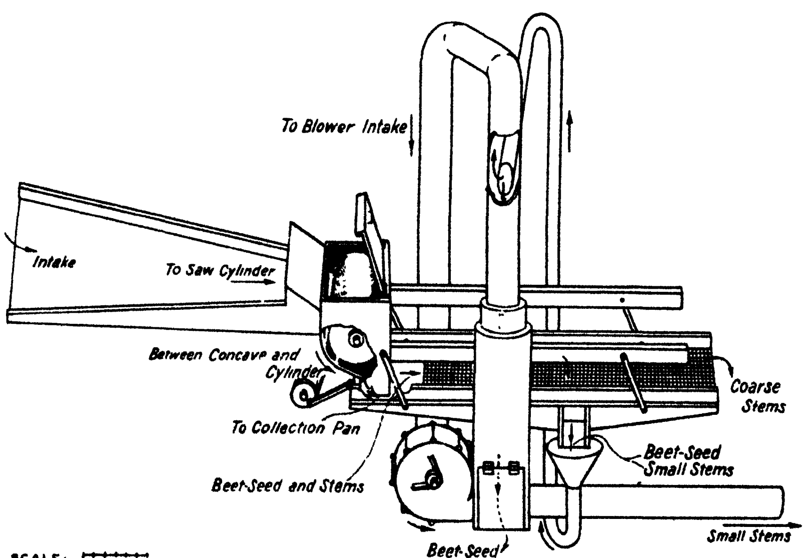

FIG. 4.—Diagrammatic sketch of working parts of the combination seed thresher and suction seed separator. Threshings from cylinder and concave are screened by the shaking screen, coarse material passing over. The screened seed and such stems and trash as pass through the screen move to the suction separator intake, which is also an intake for air for the blower. The up-draft in the separation chamber carries light material upward, the heavier material, chiefly seed, collecting in the seed hopper. The strength of the up-draft can be regulated by size of the opening in an air intake above the seed hopper. The small stems and light debris are blown out of the large pipe which extends horizontally to the right. Power for operation of the machine comes from a small gasoline engine. The whole apparatus is mounted on a 4-wheel trailer (cf. Fig. 1, E.).

mounted on the frame of a four-wheeled trailer. The motive power was supplied by a small gasoline engine.

In operation, the separator drafts were so adjusted that leaves, small stems, and debris, as well as very light seeds, which comprise from 25 to 35% of the bulk of field-run from the thresher, were removed. Close separation of the sugar beet seed into an acceptable heavy fraction and a light fraction to be rejected was left for subsequent seed-house handling with the suction seed separator. Under actual field conditions, it was found that this machine easily handled an acre per day of well-cured sugar beet seed from the shock.

The machine has utility for experimental plantings or for small acreages of elite seed, for which a light, portable outfit is needed. It is probable that the separator principle could be adapted to other similar jobs in which a light fraction is to be removed as a field operation from the threshed material.

GENETIC STUDIES OF HEAT AND DROUGHT TOLERANCE IN MAIZE[1]

E. G. Heyne and Arthur M. Brunson[2]

THE recent drought years in the Midwest have increased interest in developing new strains of corn which are more tolerant to drought. Hybrid corn in several instances has shown less injury under adverse weather conditions than have open-pollinated varieties. Although tolerance to drought is representative of a group of complex characters which are difficult to analyze, it is important that the plant breeder have more information concerning the mode of inheritance of such characters as an aid in carrying out a successful breeding program.

Preliminary observations have shown that striking differences occur among Kansas inbred lines of maize in reaction to drought. A complex character like drought resistance in maize is influenced by many genes which may be located in any or all of its 10 chromosomes. Hybridization with cultures containing markers for the several linkage groups, however, should indicate the location of some of the more important genetic factors influencing drought behavior.

The purpose of this study was to obtain fundamental information on the mode of inheritance of drought resistance. A study of its inheritance is difficult or impossible, except under controlled conditions, as this character is greatly influenced by several environmental factors.

Hunter, Laude, and Brunson (5),[3] and Heyne and Laude (4) reported that it was possible to distinguish among strains with respect to drought tolerance by testing seedling corn plants under controlled conditions. They obtained essentially the same order of relative resistance among strains when seedlings were subjected to artificial heat as was noted for the mature plants subjected to drought and heat in the field. In Kansas, extremely high temperatures seldom occur over a protracted period except when accompanied by deficient soil moisture. As a result it usually is impossible to differentiate accurately in the field between injury due to high temperatures and that due to insufficient moisture. The studies referred to above (4, 5) indicate that corn seedlings subjected to high temperature and low humidity under controlled conditions give a good index to the field behavior of the full-grown plants under the more complex natural conditions of a hot, dry summer. Consequently, the classification of drought resistance reported in this paper is based almost entirely upon the reaction of seedlings to high temperatures.

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 299 from the Department of Agronomy. Received for publication, August 10, 1940.

[2]Junior Agronomist and Agronomist, respectively, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]Figures in parentheses refer to "Literature Cited", p. 814.

TABLE 1.—*Drought-resistant inbred lines of maize and their behavior to natural and artificial drought.*

Inbred line	Generations selfed	Genetic constitution of the aleurone and endosperm	Height in 1937, inches	Maturity	Drought resistance in field, rank	Heat resistance in laboratory, rank	Varietal source
BS1	8	A_1 A_2 C R Pr Su y	50	Early	5	5	Blue Squaw
K10	4	A_1 A_2 c r Pr Su y	58	Medium	1	1	Pride of Saline
K39	5	A_1 A_2 C r pr Su y	64	Late	4	4	Pride of Saline
K201A	2	A_1 A_2 c r pr Su Y	85	Late	2	3	Midland
K201B	2	A_1 A_2 c r Pr Su Y	85	Late	2	2	Midland

MATERIALS AND METHODS

Strains of maize differed in their reaction to the shortage of soil moisture and high temperatures that occurred at Manhattan, Kansas, in 1936. Some inbred lines in the corn breeding nursery succumbed rather early, while others endured the drought to a remarkable degree. Although many strains failed to reach the tasseling stage, some were able to produce a few grains despite the adverse weather conditions. Five of these outstandingly resistant Kansas inbred lines were used as drought-resistant parents in crosses with susceptible genetic testers made in the winter of 1936–37. The five inbred lines are described in Table 1.

The drought resistance of K201A and K201B in the field is rated the same as they came from the same 1936 ear row. After an additional generation of selfing, however, K201B was noticeably more tolerant to controlled high temperatures than was K201A. The early inbred BS1 probably is not so much drought enduring as it is drought escaping, being so early that pollination takes place before the most severe weather conditions occur. K10 is the outstanding inbred line of the group in heat and drought tolerance.

Twenty-seven genetic testers carrying genes marking the 10 chromosomes in maize, 10 translocation stocks, and 4 sweet corn inbred lines[4] were used as the susceptible parents.

The genetic tester and translocation stocks used in the experiments are listed in Table 2. The Kansas inbred lines were crossed with these testers in the winter of 1936–37 and backcrosses were made in the summer of 1937. In addition, crosses were made between inbred lines and between single crosses of known reaction to high temperatures.

TABLE 2.—*Genes and translocations used as testers in crosses with heat- and drought-resistant Kansas inbred lines of corn.*

Chromosome and linkage group	Gene and symbol
1 *P-br*	*P*, pericarp and cob color; f_1, fine stripe; T1-4a; T1-4b.
2 *b-lg*$_1$	lg_1, liguleless; gl_2, glossy; T2-4b; T2-9a.
3 a_1-ts_4	na_1, nana; ts_4, tassel seed; T3-5b.
4 su_1-*Tu*	su_1, sugary; gl_3, glossy; T2-4b; T4-6a.
5 *pr*-v_2	a_2, anthocyanin (plant and aleurone color); pr_1, aleurone color; T3-5b; T5-7.
6 Y_1-*Pl*	Y_1, endosperm color; *Pl*, plant color; T4-6a; T6-9b.
7 *ra*-gl_1	gl_1, glossy; T5-7.
8 ms_8-j_1	ms_8, male sterile; T8-10b; T8-10c.
9 *c-sh-wx*	*c*, aleurone color; *sh*, shrunken; T2-9a.
10 *r*-g_1	*r*, aleurone color; T8-10b; T8-10c.

During the winter of 1937–38 seedlings of the backcross progenies and of the hybrids were subjected to controlled high temperatures. A room heated with thermostatically-controlled electrical units, constructed by the Agronomy Department, Kansas State College, was used in making all tests. Seven corn seedlings per pot were grown in 4-inch, unglazed clay pots containing a uniform soil mixture. Four or more pots of each strain of 20-day-old seedlings were distributed

[4]Genetic testers were furnished by Dr. E. G. Anderson, California Institute of Technology; Dr. A. A. Bryan, Iowa State College; and Dr. C. R. Burnham, University of West Virginia. The sweet corn lines were obtained from the Minnesota and Purdue Agricultural Experiment Stations.

at random in this room where they were exposed for 5 hours to a temperature of 127° to 130° F and a relative humidity of 30%. The soil was kept moist throughout the period the plants were subjected to heat. The measure of differential injury used was the estimated amount of exposed leaf and sheath tissue killed by the third day after treatment. On the tenth day after treatment, the number of plants killed was recorded and notes were taken on the recovery of the living plants.

EXPERIMENTAL RESULTS

INHERITANCE OF DROUGHT RESISTANCE

Crosses made between inbred lines of corn of known behavior to drought included combinations between resistant × resistant lines, resistant × susceptible, and susceptible × susceptible. The injury from controlled high temperature to five inbred lines and crosses among them is shown in Table 3. The general level of injury was low due to moderate temperatures during these tests.

The resistant × resistant cross was as resistant as its parents and was the most resistant of the crosses. In other tests at higher temperatures it was superior in drought resistance to the parents. The injury to resistant × susceptible crosses was variable, but resistance tended to be partially dominant. In the cross between the two susceptible lines, K249 and P39, the F_1 had as much tissue killed as did the two inbred parents, but fewer plants were killed. In the cross P39 × P51, the F_1 (Golden Cross Bantam sweet corn) was as susceptible to heat as the parents were, which shows that heterosis, *per se*, does not necessarily make the F_1 heat tolerant. Not all crosses reacted similar to those shown in Table 3. K249, when crossed with lines classified as being intermediate in drought resistance, produced plants that were as susceptible to heat as was K249. Line K249 appeared to carry factors for leaf burning which were often expressed in the F_1. K10 apparently has a dominant gene or genes for heat

TABLE 3.—*Comparative heat injury to seedlings of drought-resistant and drought-susceptible inbred lines and crosses among them after controlled high temperature treatment.**

Strain	Drought classification	Tissue killed, %	Plants dead, %	Recovery
K10	Resistant	6	0	Good
K148	Resistant	4	0	Good
P39	Susceptible	39	21	Poor
P51	Susceptible	48	33	Poor
K249	Susceptible	42	13	Live plants recover quickly
K10×K148	Resistant×Resistant	5	0	Excellent
K10×K249	Resistant×Susceptible	6	0	Fair
K10×P39	Resistant×Susceptible	15	0	Fair
K148×K249	Resistant×Susceptible	25	0	Slow recovery
K148×P39	Resistant×Susceptible	10	0	Fair
K249×P39	Susceptible×Susceptible	43	2	Very yellow: slow recovery
P39×P51	Susceptible×Susceptible	50	35	Poor

*Average of three experiments.

tolerance, as shown by its consistent tendency to increase the heat tolerance of the crosses in which it is involved.

The inheritance of heat tolerance also was studied in the three possible double crosses among three single crosses of known reaction. The three single crosses used had a wide range in heat tolerance. The double crosses and single crosses were tested at the same time. The data presented in Table 4 show that the double crosses differ in heat tolerance. The range in tissue injury was small, but there were large differences in the percentages of plants killed by the treatment. The double crosses were intermediate between their parental single crosses in heat tolerance.

TABLE 4.—*Comparative heat tolerance of seedlings of single crosses and double crosses under controlled high temperature conditions.*

Strain	Drought classification	Tissue killed, %	Plants dead, %	Recovery
KYS×38-11	Resistant	85	14	Fair
Hy×R4	Intermediate	94	23	Good
P39×P51	Susceptible	100	88	Poor
(KYS×38-11)×(Hy×R4)	Resistant×Intermediate	94	24	Good
(KYS×38-11)×(P39×P51)	Resistant×Susceptible	91	33	Fair
(Hy×R4)×(P39×P51)	Intermediate×Susceptible	96	45	Fair

LINKAGE EXPERIMENTS

In testing for the possible association of major genes for heat and drought tolerance with particular chromosomes, the Kansas drought-resistant inbred lines were crossed with stocks carrying genetic factors that could be identified by endosperm or seedling characters. Such factors were not available in chromosome 8, and the initial cross involving chromosome 3 was unsuccessful. The data obtained from the heat tests of backcross progenies of the crosses made are shown in Table 5.

Drought-resistant inbred lines also were crossed to lines carrying translocations and the F_1 plants were outcrossed to suitable stocks. These populations also were tested under controlled heat conditions, but no differences were observed. The backcrossed populations were planted in the field in 1939, but the growing conditions were so severe that it was impossible to classify the pollen for sterility. The use of translocation stocks is an additional tool for studying the inheritance of genes controlling quantitative characters, its value having been demonstrated in disease-resistance studies reported by Burnham and Cartledge (1).

The significance of the differences between the percentages of tissue injury in the segregating populations was determined by comparing the F values computed from analysis of variance of these data with those in Fisher's (2) table of F values. The experiments were set up so as to measure any significant differences between the gene pairs tested, between the tests, and in interaction between genes and tests. When the two classes of segregates from a cross differed significantly

in their reaction to high temperatures, it would indicate a possible linkage of the qualitative factors studied with those controlling tolerance to heat. There would be no interaction if all pairs tested were alike in their reaction to controlled high temperatures. A significant discrepancy would indicate one of two possibilities: (a) The pairs differed in relative percentage of injury at various temperature levels, or (b) as different parents were used, it might show that some lines reacted differently from others. The percentage of plants killed was not analyzed because it was not as good a measure of difference as percentage of leaf tissue burned.

TABLE 5.—*Relation of heat tolerance to genes in eight linkage groups in maize in progenies obtained by backcrossing the F_1 plants of susceptible testers × resistant inbreds to the susceptible testers.*

Genes tested		Tissue killed, %		F values from an analysis of variance of the data on tissue injury			Plants killed, %	
X	x	X	x	Computed	5%	1%	X	x
				Chromosome 1				
F_1	f_1	88	92	3.10	4.41	8.28	16	50
				Chromosome 2				
Gl_2	gl_2	70	46	11.87†	4.75	9.33	18	9
				Chromosome 4				
Su_1	su_1	87	95	29.30†	3.89	6.76	42	72
				Chromosome 5				
A_2	a_2	67	72	2.23	4.03	7.17	17	11
Pr	pr	79	88	20.39†	4.03	7.17	21	33
				Chromosome 6				
Y_1	y_1	78	83	1.74	4.26	7.82	7	11
				Chromosome 7				
Gl_1	gl_1	92	73	77.00†	4.03	7.17	34	24
				Chromosome 9				
Sh	sh	62	65	1.44	4.17	7.56	4	11
C	c	87	93	6.80*	4.08	7.31	53	71
				Chromosome 10				
R	r	90	92	1.60	4.03	7.17	55	61

*Significant difference.
†Highly significant difference.

No significant difference was observed between the gene pairs tested that are located on chromosomes 1, 6, and 10, as shown in Table 5. Significant differences in heat tolerance were obtained in segregating families involving gene pairs located on chromosomes 2, 4, 5, 7, and 9. These differences are discussed under their respective linkage groups.

Linkage group 2.—Two genes, lg_1 and gl_2, were used to determine whether genes controlling drought resistance are located on this

chromosome. Although the glossy factor entered the cross from the susceptible parent, the glossy segregates were more tolerant to heat than the non-glossy segregates as indicated by the highly significant difference. The percentage of survival also favored the glossy seedlings. The resistant inbred parent, however, was considerably more resistant than the glossy linkage tester used as the other parent of the original cross. The surface of the leaves on the glossy plants might reflect more heat rays than the leaves of the non-glossy plants, keeping the leaves cooler and causing less damage. It is also possible that the abnormal leaf surface of the glossy plants might affect transpiration rates and thereby result in the cooling effect of evaporation, or it might alter the rapidity with which lethal dessication is reached. Obviously the differential injury observed is due to morphological dissimilarity and not to genetic linkage.

Tests involving liguleless-1 indicated no association between this locus and heat reaction.

Linkage group 4.—The pair of genes determining the sugary or starchy texture of the endosperm is located in this linkage group. The sugary gene (su_1) when homozygous produces the endosperm characteristic of sweet corn. Extensive data from five segregating progenies in 32 tests show that the sugary factor is associated with heat susceptibility. Although only a small difference in percentage of leaf burning is shown in Table 5, it is highly significant. The seedlings from the sugary kernels had a much lower survival value than did the seedlings from the starchy kernels. Typical pots from segregating progenies are shown in Figs. 1 and 2.

Crosses were made in which gl_3 and su_1 were contributed by the susceptible parent. Since these two genes are about 40 units apart on

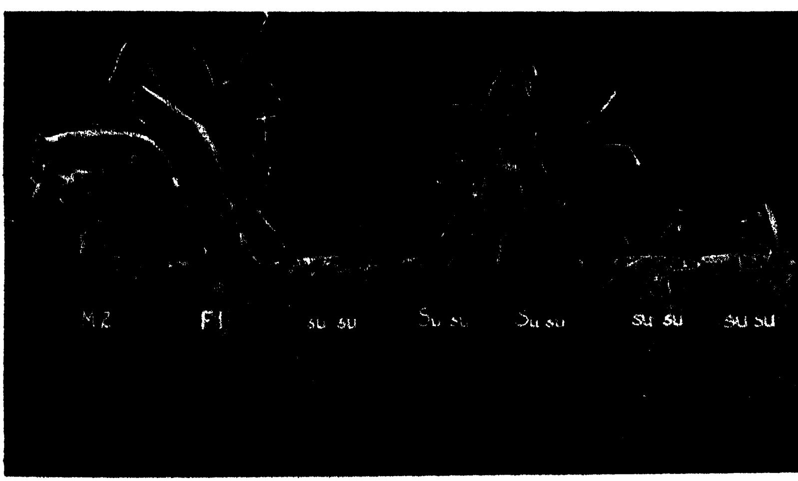

FIG. 1.—Effect of heat on maize plants segregating for starchy and sugary kernels. The parents are represented by the first and third pots, and the F_1 is between them. The starchy and sugary segregates resulting from a backcross to the *susu* parent are represented by the *Susu* and *susu* plants, respectively.

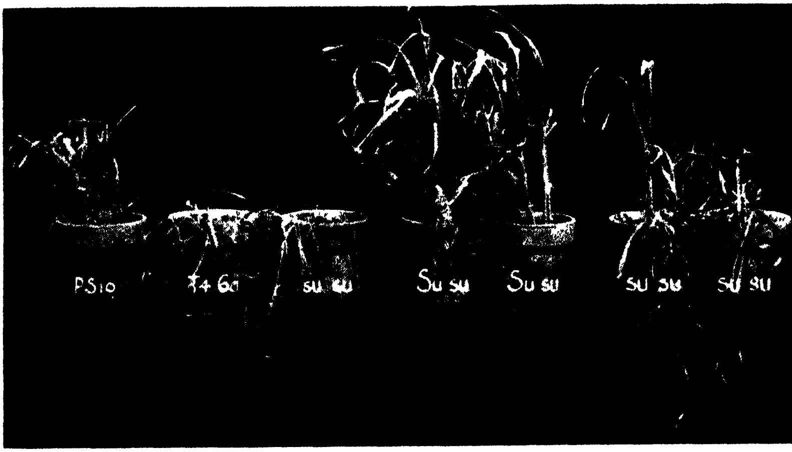

FIG. 2.—Relative heat tolerance of a starchy inbred and sugary translocation and the resulting progeny when outcrossed to a sugary stock. PS10 is the resistant parent, T4-6a is the susceptible translocation parent. The third pot from the left, *susu*, is the stock to which the F_1 (not shown) was outcrossed. The four pots on the right represent the segregating progeny, *Susu* designating plants from the starchy segregates and *susu* those from the sugary segregates.

the chromosome, frequent crossovers would be expected. Starchy glossy, starchy non-glossy, sugary glossy, and sugary non-glossy plants were tested at the same time. The sugary seedlings in both cases were more susceptible than the starchy segregates. There was no significant difference in heat tolerance between the starchy glossy plants and the starchy non-glossy plants. The sugary non-glossy plants, however, were slightly more resistant to heat than the double recessive condition, *su* gl_3. This is not in agreement with the apparent morphological relation of glossy leaves with heat tolerance obtained with gl_1 and gl_2.

Sweet corn as a class is generally more susceptible to drought injury than is dent corn, which suggests that the sugary gene itself may be responsible. This was indicated when plants heterozygous for translocation stock T1-4a were grown to the pollen shedding stage. The translocation T1-4a, heterozygous for sugary (*Susu*), was crossed to a resistant inbred line (*SuSu*). The sugary condition was not expressed in the F_1, but one-half of the ears from F_1 plants outcrossed to *su* stock segregated for sugary endosperm. When the sugary and starchy segregates from one of these segregating ears were tested, the seedlings from the sugary kernels were more heat susceptible. The outcross, not involving the *su* gene, also was planted and subjected to heat. The 16 most resistant plants from 56 tested were transplanted and grown until they shed pollen. Only 12 plants lived. If a gene responsible for heat susceptibility is located on chromosome 4 near the translocation, one would expect all the plants to be normal; however, 7 of the 12 plants were semisterile and five normal. Although small numbers were used, it indicates that heat susceptibility is not due to genes on chromosome 4 other than the factor pair *Susu*.

It is probable that *su* gene itself affects drought tolerance in a manner similar to that of other genes in maize that are known to have manifold effects on unrelated structures or functions of the plant. In the tests conducted, no sweet corn lines were found to be resistant to heat.

Haber (3) exposed 20-day-old seedlings to controlled high temperature and low humidity and observed differences in resistance to heat among sweet corn strains, but the most resistant strains of sweet corn were not so resistant as resistant strains of dent corn. If the *su* gene is responsible for the lower resistance to heat, it will be a limiting factor in the production of a sweet corn possessing as high a degree of resistance as is found in lines of starchy corn.

Parallel crosses made in this experiment indicate that the parental inbred lines differed in genetic factors influencing reaction to heat which they transmitted. When two inbred lines were crossed on the same sugary tester and backcrossed to the same stock, evident differences occurred in the reaction of the progenies to heat. This difference is illustrated clearly in Fig. 3. The time of planting and treatment were identical. K10 transmitted more heat resistance to its progeny than did BS1. Even the plants from the sugary kernels showed considerable resistance to heat when K10 was involved, while the plants from sugary kernels were killed when BS1 was used as a parent. Line K10 showed more resistance to heat than did BS1 when subjected to the same conditions. Evidence of a wide range of heat and drought resistance in maize, together with proof that differences are inherited, indicate that progress can be made in breeding better heat- and drought-resistant strains.

Linkage group 5.—The behavior of heat tolerance was determined in relation to two genes in this group, a_2 and *pr*. The data presented in Table 5 indicate that the A_2, a_2 pair of genes probably is inherited independently of heat tolerance. Although the a_2 tester used was one of the testers that gave an intermediate reaction to controlled high temperatures, enough plants were tested so that even a loose linkage should have shown a significant difference as determined by analysis of variance.

The seedlings involving the *Prpr* pair of genes gave highly significant results for heat tolerance. In the cases studied *Pr* came from the resistant parents and the *Pr* segregates produced the most resistant seedlings. The survival value is also in favor of the *Pr* plants.

Linkage group 7.—As shown in Table 5, gl_1 appears to affect the relative heat tolerance of corn seedlings. In segregating progenies the glossy seedlings were more resistant to heat than the non-glossy seedlings. This substantiates the results with linkage group 2 in which the glossy seedlings, due to gl_2, also were the more resistant, although the glossy character came from the susceptible parent.

Since the glossy testers used as parents were more susceptible to heat than the non-glossy resistant inbred lines, it would be expected that if a linked factor for heat behavior were involved, the glossy seedlings should be most susceptible in the segregating progenies resulting from backcrosses to the recessive parents.

Linkage group 9.—The relation of heat tolerance to two pairs of

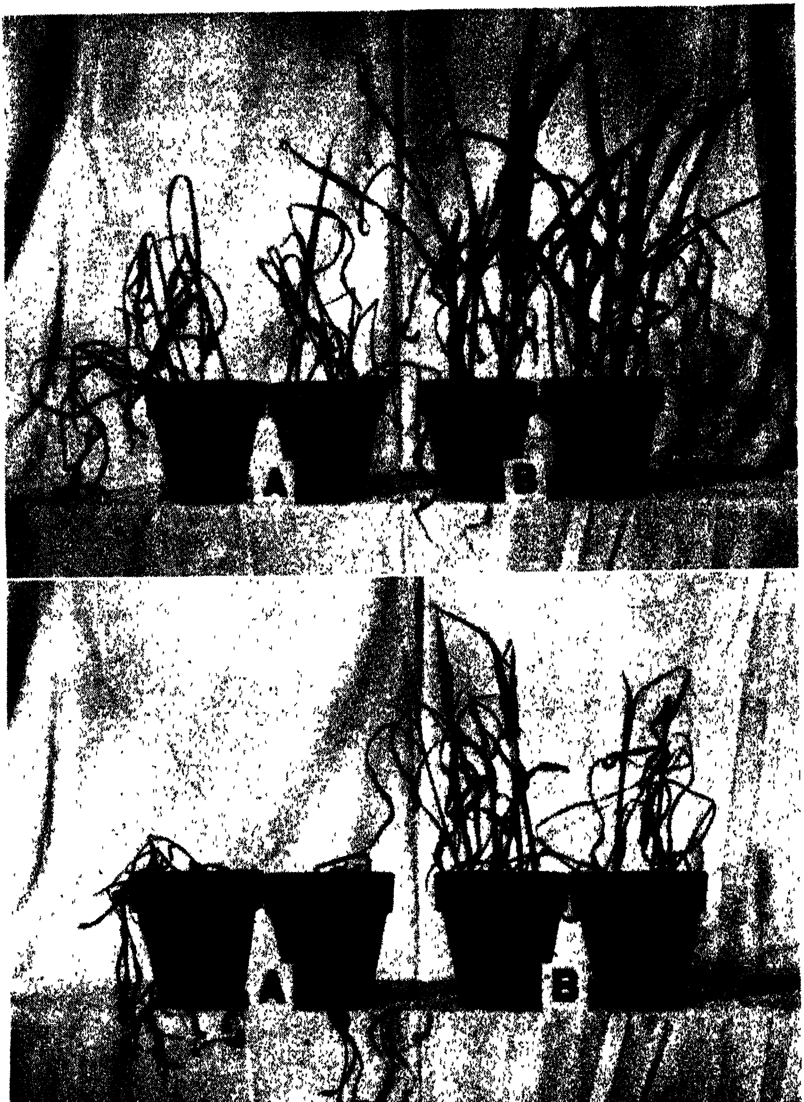

FIG. 3.—Effect of different parents on the heat resistance of their progeny. The plants were grown and treated under comparable conditions. Heat resistance transmitted by K10 (upper) is much more pronounced both in sugary segregates (A) and starchy segregates (B) than that transmitted by BSl (lower).

genes, *Shsh* and *Cc* on this chromosome was studied. The shrunken factor causes the endosperm to collapse during drying at maturity and the seedlings are somewhat retarded in early stages of growth. Although the seedlings from shrunken kernels may have been at a

disadvantage, no significant differences between this pair of genes in percentage of heat injury occurred.

In tests with the *Cc* pair of genes, which affect aleurone color, a significant difference in heat tolerance was obtained using percentage of leaf injury as a criterion. The *C* factor entered the cross with the resistant parent. The results were barely significant (odds 19 to 1), and it may have been that only a fortuitous choice of material was responsible for the observed difference. The difference in survival, however, is considerably in favor of the *C* factor. One of the more striking differences occurring in this pair of genes is illustrated in Fig. 4.

FIG. 4.—Segregates from a backcross showing differential response to controlled high temperatures of seedlings from colorless (*c c*) and colored (*C c*) kernels due to the *C c* pair of genes. The dominant *C* factor came from the heat-resistant parent in the original cross.

The short distance on the chromosome map between the loci for *Cc* and *Shsh* makes it difficult to explain on a basis of simple linkage relationships why heat tolerance was associated only with the *Cc* pair. Possibly an unknown gene for heat tolerance in the ninth linkage group may have been involved in one cross and not in the other. Another possibility is that the *Cc* factor pair itself might have some direct influence on heat tolerance.

SUMMARY

Inheritance of tolerance to heat and drought was studied in selfed lines of corn and crosses among them. Heat tolerance was definitely inherited and, in most of the cases studied, was intermediate to dominant. Hybrid vigor, in itself, apparently does not make a cross resistant to heat, at least in the seedling stage.

Linkage relations were studied between one or more factors in 8 of the 10 linkage groups and the possible factors determining heat tolerance. Close associations of heat tolerance with the Su_1su_1 and *Prpr* and a possible association with *Cc* loci were observed. The effects of gl_1 and gl_2 in the seedling stage apparently protect the corn seedlings

from injury by artificial heat, while the factor gl_3 probably does not possess this protective quality.

The *su* gene is considered to be directly responsible for susceptibility to heat injury as shown by the behavior of seedlings from sugary and starchy kernels. The equal distribution of the semi-sterile and normal plants among those tolerant to heat from a backcross involving chromosome 4 strengthens this belief.

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NOTES

THE USE OF PUNCHED CARD EQUIPMENT IN PREDICTING THE PERFORMANCE OF CORN DOUBLE CROSSES[1]

IN 1934, Jenkins[2] presented data comparing four methods of predicting the performance of double-crossed corn hybrids. Since that time his method B, which utilizes information on the four non-parental single-crosses, has been verified by several investigators and found quite satisfactory. This method is now used widely, but the labor involved in assembling and averaging the results from extensive single-cross tests without the aid of punched card equipment has proved a considerable task.

The corn breeding project at Ames, Iowa, has made extensive use of punched card equipment in the tabulation of yields, sums of squares, etc., for the past several years. Using the punched card equipment available in the Statistical Laboratory of the Iowa State College, the following method of predicting double-cross performance has been found quite satisfactory and much more rapid than hand tabulation.

The single-crosses involved in any particular test were written down in systematic order, as follows: First the six singles which can be produced from four inbreds, then the four additional singles which can be made when the fifth inbred line is added, etc. After this process was completed the single-crosses were numbered consecutively The numbers are the single-cross code numbers used in sorting and tabulating.

The next step was a similar systematic listing of all possible double-crosses; first the three double-crosses which can be made among four inbred lines, then the 12 additional double crosses possible when a fifth line is added, etc. Using letters of the alphabet to designate inbred lines rather than actual pedigrees, pedigrees have been prepared for all possible combinations among 16 inbred lines. The listing of single-cross and double-cross combinations in the systematic order indicated permits the use of the same coded pedigrees for any set of single crosses involving all possible combinations of 16 or fewer lines. All possible single-cross combinations among 13 or 16 lines can be handled readily in 9×9 or 11×11 lattice square designs, respectively, which we have found to be quite satisfactory for corn yield comparisons.

After the key list of double-cross pedigrees was prepared the single-cross code numbers of the four non-parental single crosses were obtained from the systematically listed single crosses and recorded on the same sheet with the double-cross pedigrees, as illustrated below:

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[1]Journal Paper No. J-785 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 163. Contribution from the corn improvement program at Ames, Iowa, conducted by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, in cooperation with the Farm Crops Subsection, Iowa Agricultural Experiment Station.

[2]JENKINS, M. T. Methods of estimating the performance of double-crosses in corn. Jour. Amer. Soc. Agron., 26:199–204. 1934.

Single-crosses	Double-crosses	Non-parental Singles
1 a × b	(a × b) (c × d)	2, 3, 4, 5
2 a × c	(a × c) (b × d)	1, 3, 4, 6
3 a × d	(a × d) (b × c)	1, 2, 5, 6
4 b × c		
5 b × d		
6 c × d		

When the calculations are completed for any single-cross test, the code numbers and the data for all variables used in prediction are punched on cards, one for each single-cross combination. Following verification these are run through the duplicator to obtain 10–20 cards for each cross. A total of 182 cards would be necessary for each single-cross combination if no resorting is to be done and the test involved all possible combinations of 16 lines. The cards are then sorted on the single-cross code numbers and laid out in consecutive order. One operator calls off the proper single-cross code numbers from the double-cross pedigree sheets and the second operator picks up the cards. A blank card is inserted after each set of four single crosses (one double cross). When the supply of cards of any one single-cross code number is exhausted, the assembled cards are placed in the tabulator and the data for each single cross and the totals for the sets of four crosses are listed. After the cards pass through this machine they are resorted and the assembling process continued until all possible double-cross combinations have been made. It is then a simple process to replace the double-cross code pedigree with the actual pedigree and to divide the totals of each set by four. These values then represent the predicted performance of the double cross for each of the variable studies. To simplify the procedure and reduce the labor involved, any lines consistently giving poor performance should be omitted before predictions are undertaken.

The use of punched card equipment merely provides an easy method of making a number of copies of the data for each single cross, of assembling the desired single crosses, and of obtaining the totals for each variable studied.

Where punched card equipment is not available the following procedure may be used advantageously: A number of copies of the single-cross data may be obtained by means of a mimeograph. These sheets may then be cut into strips, with the data for one single cross on each strip. The four single crosses involved in the prediction of each double cross can then readily be assembled and the prediction values determined. Either of these procedures will eliminate the necessity for repeated copying with all the labor and possibility of errors which such work involves.—AMY MILLANG AND G. F. SPRAGUE, *Iowa State College, Ames, Iowa.*

AN ELECTRICAL RESISTANCE METHOD FOR MAKING CONTINUOUS MEASUREMENT OF MOISTURE IN CONCRETE PAVEMENTS AND IN SOILS UNDER ROAD CONDITIONS

IN PREVIOUS communications,[1] an electrical resistance method was presented for making a continuous measurement of soil moisture under field conditions. The method made use of a plaster of paris block in which were imbedded two electrodes, and a special form of the Wheatstone bridge. The principle of the method was based upon the following facts:

1. The plaster of paris block takes up and gives up water very readily, so that it tends to maintain a close moisture equilibrium with its environment.
2. The electrical resistance of the plaster of paris block is inversely proportional to its water content, so that by calibration the electrical resistance becomes an index of moisture in soils or in concrete.
3. The comparatively high solubility of plaster of paris, which is 2,200 to 2,400 p.p.m., tends to act as a buffer and minimizes the influences of salts.
4. By imbedding the electrodes in a uniform and constant material such as plaster of paris, the uncertainties and errors which arise from differences in texture, composition, compaction, salt content, etc., of the medium surrounding the electrodes, are eliminated or greatly minimized, and the results thereby become more reliable and accurate.

The method as applied to soil has proved satisfactory. In the present note, it is the purpose to call attention to the possible application of the method to the measurement of moisture in concrete pavements under field conditions, and to other studies connected with concrete and soils.

It has been found that the method is capable of making a continuous measurement of moisture in concrete from the saturation point down to the air-dry condition, as the figures in Table 1 show.

TABLE 1.—*Relationship between electrical resistance and moisture content in concrete*

Resistance at 70° F, Ohms	Moisture, %
285	10.3 (saturated)
355	9.3
2,500	8.7
5,800	7.3
18,000	6.5
38,000	5.5
75,000	5.1
200,000	3.9
1,000,000	3.3 (air dry)

[1]Science, 89: 252. 1939. Mich. Agr. Exp. Sta. Tech. Bul. 172. 1940.

These results were obtained in the laboratory by casting around the plaster of paris block a shell of mortar ¼ inch thick. This mortar was made up by mixing in the following proportions by weight 50 parts of water, 100 parts Huron cement, and 200 parts of sand passing 2-mm sieve. After the mortar had been properly cured, it was allowed to dry at room temperature to different degrees of dryness, as indicated by the electrical resistance readings.

In order that the mortar shell might have a uniform moisture throughout its thickness, the entire block was wrapped in oiled paper and allowed to stand for 24 hours or longer. The resistance reading was then taken, the mortar shell broken off from the plaster of paris block, and its moisture determined by drying it at 100° C for 24 hours.

Other cells besides plaster of paris cells have been tried with the method, but the plaster of paris cells have proved to be the most satisfactory. The other cells tried consisted of fired clay, builder's cement, various concretes, cement and plaster of paris, marble dust with various binders, dental casting compounds, Keene's cement, and various commercial plasters (Alabatine, Alabastone, etc.).

Air-dry condition seems to be the lowest degree of moisture that the method is capable of measuring. The moisture content at the air-dry condition may vary somewhat, depending upon the variation in temperature and humidity, as well as upon composition of the mortar.

It would seem that a part of the moisture contained in concrete in the air-dry condition is water which is probably held with great chemical or physical forces and can only be determined by expelling it at high temperatures.

In order to measure such low moisture contents in concrete and in soils, a special electrical bridge has been developed which can be used to read very high resistances. This bridge is portable and weighs about 15 pounds. A vacuum tube oscillator, powdered by dry cell batteries, supplies alternating current at high frequency, eliminating polarization and electrolysis errors. The capacitance introduced by the plaster of paris block is balanced out by a variable condenser.

Besides measuring moisture, this electrical resistance method can also be used to ascertain whether or not the concrete or the soil is frozen. It has been found that when the water freezes the resistance jumps from about 500 ohms to about 50,000 ohms.

From all tests thus far made it seems that the method is satisfactory in making a continuous moisture measurement of soils and of concrete pavements at any depth under field conditions.

A detailed report of laboratory and field study of the method will be made by the Research Division of the Michigan Highway Department.—GEORGE BOUYOUCOS, *Soils Section, Michigan State College, East Lansing, Mich.*

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ORGANIC CARBON, pH, AND AGGREGATION OF THE SOIL OF THE MORROW PLATS AS AFFECTED BY TYPE OF CROPPING AND MANURIAL ADDITION[1]

R. S. STAUFFER, R. J. MUCKENHIRN, AND R. T. ODELL[2]

THE physical condition of soils under cultivation undergoes various changes, the nature and extent of which seem to depend largely upon the system of cropping and management practiced. The study here reported of the soil of the Morrow plats was concerned with the aggregation and organic carbon of this soil, particularly in relation to the results of a previous study by Stauffer (8).[3]

A review of the factors affecting soil structure has been published by Russel (7), and numerous recent investigators have dealt with changes in the porosity, organic matter content, and permeability of soils.

Browning (1), using the wet-sieving method of analysis, found that organic matter when added to soils of relatively poor structure increased the number of the larger sized aggregates. Bluegrass sod contained a much higher percentage of coarse aggregates than cultivated land. He reported, however, that the organic-matter content of some soils was considerably increased without increasing aggregation markedly, although the infiltration and percolation rates of these soils were usually increased.

Puhr and Olson (6), after using both the wet-sieving and the hydrometer methods of aggregate analysis on several South Dakota soils, concluded that cultivation had not had a pronounced effect on soil structure, even though it had caused a loss of 42% of the original organic matter.

Metzger and Hide (5) found with Kansas soil that different crops has measurably different effects on aggregation, and that the more aggregated portions of the soil contained significantly more organic carbon than the less aggregated portions.

[1]Contribution from the Division of Soil Physics, Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director of the Illinois Agricultural Experiment Station. Received for publication June 27, 1940.

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[3]Figures in parentheses refer to "Literature Cited", p. 831.

THE MORROW PLATS AND THE PLAN OF THE INVESTIGATION

The Morrow plats, established at the Illinois Agricultural Experiment Station in 1876, have had the present cropping system since 1904. The plats are 2 rods wide and 4 rods long with ½ rod borders cropped like the adjacent plats between them. Fig. 1 shows a diagram of the six plats studied and gives the symbols or abbreviations to be used in this article in referring to the plats. The word "Sod" will refer to the grassed area surrounding the entire system of plats.

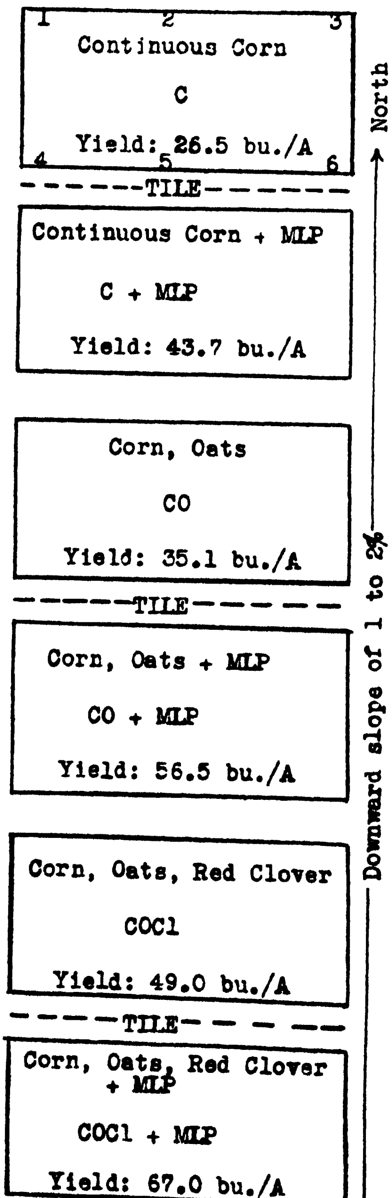

FIG. 1.—Diagram of Morrow plats, showing cropping systems, soil treatment, and corresponding symbols: slope, tile lines, average yields for the eight seasons since 1893 when corn was grown on all plats at the same time, and, in the C plat, the six sampling locations.

No fertilizers were used on these plats until 1904. Two tons of manure were applied per acre per year to the fertilized (MLP) plats from 1904 to 1909, and, since then, a weight of manure equal to the air-dry weight of the crops removed has been applied annually. In 1904, 1,704 pounds of limestone were applied per acre to the MLP plats and 5 tons more in 1919. Rock phosphate was applied per acre to the MLP plats as follows: 600 pounds yearly from 1904 to 1918, 3,000 pounds in 1919, and 200 pounds from 1920 to 1925. Further information on these plats is given by DeTurk, Bauer, and Smith (3) and by annual bulletins of the Illinois Agricultural Experiment Station.

The soil of the plats, a prairie type, was formerly called Carrington silt loam (8), but the drift underlying these plats is found at greater depths and is not leached as deeply as that usually found under the Carrington soils, so that name is no longer used. Some outwash may have been mixed with the loessial parent material on these plats.

Samples were taken on the plats before plowing in the spring of 1938 at uniformly measured distances from the ends and sides of each plat at six locations (Fig. 1). All plats had been in corn in 1937. The sod border had been in sod

since 1904. The sod border was sampled at a distance of 2 to 3 feet from the west end of each plat. At each location the soil was sampled at arbitrary depths of 0 to 6, 6 to 9, 9 to 13, and 13 to 18 inches, and each sample was stored and analyzed individually. For the 0 to 6 and 6 to 9 inch depths a 3-inch volume-weight cylinder was driven slowly into the soil to determine volume weights and to secure samples at the same time. For the other two depths a 2½-inch auger of the post-hole type was used. An auger even of this type is not desirable for taking samples for aggregate analysis, but it was necessary in this case to minimize the possible damage to the plats. It was originally intended to limit the study to the A horizon. This was not done, however, since the A horizon was more shallow than expected on the C and C plus MLP plats, as will be mentioned later in this article.

The samples were air dried and stored in glass fruit jars. After thorough mixing, each individual sample was analyzed for carbon, pH, and aggregation. The pH was determined on each sample by means of a glass electrode, using a mixture of 4 grams of soil and 2.4 cc of distilled water. Total carbon determinations were made by the method of Winters and Wimer (10) and mechanical analyses by a method similar to that of Winters and Harland (11). The samples from two locations on each plat were analyzed mechanically, with the exception of the COCl plat in which case the samples from all six sampling locations were analyzed.

Aggregate analyses were made by a wet-sieving method similar to that described by Yoder (12). Wet-sieving is not dependent on the settling velocities of the aggregates and so has advantages over other methods of aggregate analysis (12). The results of aggregate analyses depend to a considerable extent upon the pretreatment of the samples (1, 12) and even upon the time of year the samples are taken (1, 4, 7).

Three sizes of sieves were used, *viz.*, Nos 35, 60, and 140, with nominal openings of 0.50, 0.25, and 0.10 mm, respectively. A fourth fraction, 0.10 to 0.05 mm in diameter, was obtained by sedimentation in beakers. The time of settling was taken as 40 seconds for a depth of 10 cm. No adjustment for varying water temperature, which was approximately 20° to 22° C, was made because of the uncertainties in calculating the rate of aggregate sedimentation (12). The National Bureau of Standards' specifications for "standard" sieves allow the following tolerances for Nos. 35, 60, and 140: For the maximum opening 25, 40, and 60%, and for the average opening 5, 6, and 8%, respectively. In this investigation, all the No. 35 sieves used had been made with the intention of meeting the National Bureau of Standards' specifications, as were the No. 60 sieves used on the samples from the 0 to 6 and 6 to 9 inch soil depths. "Routine" or "general purpose" sieves were used for the No. 140 on all samples and for the No. 60 on the 9 to 13 and 13 to 18 inch depths. One large supply house estimated the tolerances of such sieves to be about twice those of the "standard" grade, which are considerably more expensive, and, though desirable, are probably not necessary.

The machine used to raise and lower the sieves consisted of an electric motor and suitable shafts and pulleys mounted on a table. It raised and lowered six nests of three sieves each through a distance of 1¼ inches 25 times a minute (50 oscillations or single movements per minute) for a period of 30 minutes. The sieves were set in such a way that at the bottom of the down stroke the upper rim of the top sieve was just above the surface of the water. The rate of 25 upward movements per minute was sufficiently slow to allow 1¼ inches of water to drain through the sieves each time, and yet it was probably not fast enough to produce any undesirable dispersion; in fact, the larger aggregates resting on the top sieve were not raised off the wire cloth by the force of the water during the down stroke.

There was no indication during the determinations that the variation in temperature (about 4° C from the average) of the distilled water used affected the results.

All aggregate analyses were made in duplicate and the agreement found between duplicates was generally good. When any two fractions of the duplicates varied more than 10% from the average of the two, the analysis was repeated and the average of the triplicates taken as final. Of the 168 samples analyzed in this investigation, only 18 had to be re-analyzed to meet the above requirement. The aggregates were dried at 105° C and the percentages of the various sized aggregates were calculated to the nearest tenth of 1% on the basis of the amount of oven-dry soil used for analysis (about 25 grams). From this percentage of aggregates of any given size was subtracted the percentage of sand of that size in the soil as determined by mechanical analysis. Hence the aggregates reported in Tables 5 and 6 include no sand particles of equal or greater size, and the percentages of aggregates are minimum values. Some of the fine sand, for instance, undoubtedly occurred in aggregates of medium sand size, but the entire percentage of fine sand was nevertheless subtracted from the weight of sand and aggregates of fine sand size.

RESULTS AND DISCUSSION

TEXTURE

The mechanical analyses (Table 1) show that the soil of these plats is very uniform in average physical composition. On the COCl plat, however, the samples from location 1 were markedly higher in sand than samples from the other plats or even than other samples from the same plat. On this particular plat, therefore, mechanical analyses were made of the samples from each of the six sampling locations, and the results for this plat, given in Table 1, are averages of six determinations. The percentages of total sands from samples 1 and 6 on the COCl plat were, in the 0 to 6 inch depth, 11.1 and 4.9; the 6 to 9 inch depth, 14.7 and 4.1; in the 9 to 13 inch depth, 18.7 and 2.9; and in the 13 to 18 inch depth, 23.2 and 2.8, respectively. The subsoil, deeper than 18 inches, at location 1 was also more sandy than the subsoils at the other locations. Such variation is not uncommon in this morainal region and serves to emphasize the importance of care in sampling soils.

pH VALUES

The pH of the soil of plats treated with ground limestone at the rate of 1,705 pounds per acre in 1904 and 5 tons in 1919 was higher than that of unlimed plats in the 0 to 6 and the 6 to 9 inch depths (Table 2, Fig. 2). In the upper 9 inches, the arithmetical average of the pH ranged from 4.81 to 5.36 in the unlimed plats and from 5.52 to 6.20 in the limed plats. The average pH of the soil below 9 inches ranged from 5.35 to 5.87 and showed no material change due to liming. However, the high value of 5.87 for 6 determinations in the 9 to 13 inch depth on the CO plus MLP plat indicated that liming may have had some effect to a depth of 13 inches on this particular plat.

TABLE 1.—*Mechanical analyses of the soil of the Morrow plats, percentage by weight of oven-dry soil.**

Plat	>0.5 mm†	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm	Total sands, 2.0–0.05 mm	Clay <0.002 mm	Silt, 0.05–0.002 mm (by difference)
			0 to 6 Inch Depth				
C	2.1	2.0	1.3	1.8	6.9	24.7	68.4
C+MLP	1.7	1.7	1.1	1.6	5.8	24.8	69.4
CO	2.2	1.6	1.1	1.6	6.4	25.6	68.0
CO+MLP	2.3	2.2	1.9	1.5	7.8	25.7	66.5
COCl	2.0	1.9	2.2	1.9	7.8	25.6	66.6
COCl+MLP	1.7	1.7	1.1	1.6	6.0	25.0	69.0
			6 to 9 Inch Depth				
C	2.0	1.6	1.0	1.4	5.3	26.6	68.1
C+MLP	2.3	1.3	0.9	1.3	5.3	26.4	68.3
CO	1.6	1.5	0.9	1.2	5.0	27.3	67.7
CO+MLP	2.3	1.8	1.4	1.3	6.4	26.2	67.4
COCl	1.5	1.9	2.1	1.5	7.0	26.2	66.8
COCl+MLP	1.3	1.6	1.0	1.3	5.0	26.9	68.1
			9 to 13 Inch Depth				
C	1.5	1.2	0.8	1.2	4.4	28.6	67.0
C+MLP	1.4	1.4	0.8	1.2	4.6	28.2	67.2
CO	1.4	1.3	0.8	1.0	4.5	27.0	68.5
CO+MLP	1.8	2.2	1.3	1.4	6.0	25.3	68.7
COCl	1.6	2.0	2.1	1.5	7.1	27.0	65.9
COCl+MLP	1.0	1.3	0.8	1.0	4.0	28.6	67.4
			13 to 18 Inch Depth				
C	1.3	1.2	0.7	1.1	3.7	31.7	64.6
C+MLP	1.0	1.2	0.8	1.1	4.0	31.1	64.9
CO	1.7	1.2	0.8	1.2	4.3	29.1	66.6
CO+MLP	1.7	2.1	1.4	1.6	6.7	26.3	67.0
COCl	1.8	2.3	2.5	1.6	8.0	28.4	63.6
COCl+MLP	1.0	1.3	0.9	1.0	4.0	26.3	69.7

*Averages of two samples per plat except for COCl plat in which six samples were analyzed and averaged. The letters C, O, and Cl signify corn, oats, and clover, respectively, and MLP the soil treatment of manure, lime, and rock phosphate.

†Includes a small amount of material larger than 2 mm in diameter

TABLE 2.—*Average pH and range in pH of six samples from each of four depths on each of the Morrow plats.**

Plat	0–6 inch		6–9 inch		9–13 inch		13–18 inch	
	Average	Range	Average	Range	Average	Range	Average	Range
C	4.81	4.96–4.53	5.36	5.70–4.97	5.63	5.91–5.40	5.79	6.17–5.38
C+MLP	5.54	5.82–5.20	5.69	5.89–5.49	5.70	6.00–5.43	5.71	5.94–5.46
CO	4.99	5.02–4.93	5.26	5.50–5.11	5.52	5.78–5.41	5.63	5.89–5.42
CO+MLP	5.52	6.00–5.16	5.82	6.27–5.47	5.87	6.60–5.50	5.85	6.60–5.58
COCl	4.89	4.92–4.80	5.16	5.28–4.99	5.35	5.58–5.20	5.47	5.70–5.37
COCl+MLP	6.20	7.05–5.40	6.19	7.01–5.47	5.48	5.69–5.30	5.48	5.78–5.23

*In calculating the averages, the pH values were treated simply as if they were arithmetical numbers.

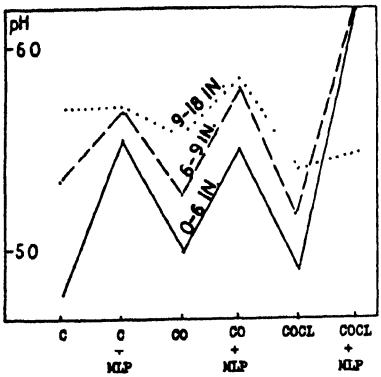

FIG. 2.—Effect of crops and soil treatment on the pH of the soil of the Morrow plats.

The pH of all plats reached a maximum in the 9 to 13 or 13 to 18 inch depths except for the COCl plus MLP plat which had its maximum in the upper 6 inches.

VOLUME WEIGHT

The fertilizers and crops used on these plats had little, if any, effect on the volume weight of the soil as measured with a metal cylinder (Table 3). Fertilization and the longer rotations appear to have decreased the volume weight slightly but consistently in the 0 to 6 inch layer, but the differences are not significant statistically.

TABLE 3.—*Average volume weight and range in volume weight of six samples from each of two depths on each of the Morrow plats and the adjoining sod.*

Plat	0–6 inch		6–9 inch	
	Average	Range	Average	Range
C	1.37	1.42–1.33	1.25	1.30–1.19
C+MLP	1.31	1.34–1.27	1.26	1.40–1.07
CO	1.33	1.38–1.28	1.30	1.36–1.22
CO+MLP	1.24	1.35–1.16	1.37	1.46–1.29
COCl	1.31	1.40–1.25	1.28	1.40–1.12
COCl+MLP	1.21	1.29–1.12	1.29	1.34–1.23
SOD	1.28	1.39–1.23	1.29	1.40–1.17

SOIL CARBON

The total carbon content of the samples, given in Table 4 and Fig. 3, is practically equivalent to the organic carbon because the inorganic carbon is negligible in amount. Only 1 of 29 samples from various depths between 0 and 18 inches had an inorganic carbon content as high as 0.01%.

The organic matter content in the upper 9 inches was maintained at a markedly high level only by the best treatment, namely, a corn-oats-clover rotation plus applications of manure, lime, and phosphate, and it was at a markedly low level only in the plat having the poorest treatment, namely, continuous corn without fertilizers. This low level under continuous corn was due, to some extent at least, to erosion, as will be discussed further in this article. The bluegrass in the sod border, undisturbed for 34 years, was no more effective than the fertilized corn-oats-clover rotation in maintaining the total carbon content of the soil (Table 4). Below 9 inches neither rotation nor soil treatment had much effect on the organic content of the soil.

TABLE 4.—*Average carbon content and range in carbon content in six samples from each of four depths on each of the Morrow plats and the adjoining sod.*

Plat	0–6 inch, %		6–9 inch, %		9–13 inch, %		13–18 inch, %	
	Average	Range	Average	Range	Average	Range	Average	Range
C	1.74	1.82–1.66	1.71	2.01–1.29	1.48	1.88–0.91	1.11	1.51–0.69
C+MLP	2.09	2.22–1.95	2.15	2.41–2.01	1.91	2.11–1.58	1.44	1.71–1.09
CO	2.14	2.18–2.09	2.16	2.31–2.05	2.04	2.39–1.80	1.70	2.14–1.40
CO+MLP	2.44	2.74–2.22	2.29	2.46–2.09	2.02	2.25–1.83	1.67	1.86–1.48
COCl	2.28	2.72–1.96	2.34	2.76–1.98	1.99	2.57–1.64	1.69	2.17–1.32
COCl+MLP	3.35	4.06–2.79	2.92	3.88–2.14	2.18	2.69–1.71	1.77	2.42–1.37
Sod	3.20	3.55–2.91	2.16	2.35–1.89	2.16	2.31–1.86	1.94	2.12–1.66

An analysis of variance showed that differences in total carbon produced by the fertilizer treatment and by the rotations are significant (1% level), and also that the depths differed in total carbon content. It also showed that the fertilizer treatment produced significantly (1% level) different results with the different rotations, and also different results in the 0 to 9 as compared with the 9 to 18 inch depths. The rotations also differed in their effects on these depths.

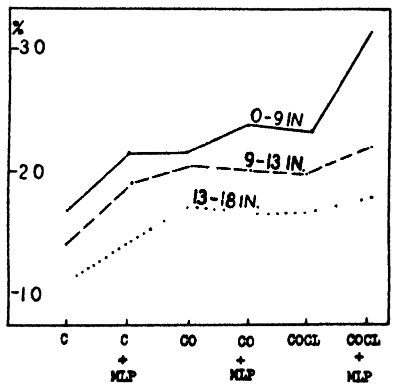

FIG. 3.—Effect of crops and soil treatment on the total carbon in the soil of the Morrow plats.

The above effects of the fertilizer treatment and rotations were analyzed statistically in more detail, and the results are summarized in Tables 5, 6, and 7. The following points are worthy of mention:

(a) The manure-lime-phosphate treatment maintained at a higher level the total carbon content of the soil above 9 inches, but it had little or no effect below 9 inches (Table 5). The difference ranged from about 1% in the 0 to 6 inch depth under corn-oats-clover to 0 below 9 inches under corn-oats.

(b) The higher total carbon content maintained by fertilizer treatment over no fertilizer was more pronounced at all depths with continuous corn and with corn-oats-clover than it was with the corn-oats rotation.

(c) The unfertilized corn-oats and corn-oats-clover rotations maintained at a significantly higher level the total carbon at all depths as compared with continuous corn. The observed amount of this increase was about 0.5% of carbon (Table 6). The unfertilized corn-oats-clover rotation was not significantly better than the corn-oats-rotation in maintaining the carbon content of the soil.

TABLE 5.—*Increase or decrease in percentage of total soil carbon produced by manure-lime-phosphate treatment on the Morrow plats under three rotations and at four depths.*

Depth, inches	Corn continuously		Corn-oats rotation		Corn-oats-clover rotation	
	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase or decrease (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*
0– 6	0.35	0.02 and 0.68	0.30	-0.03 and 0.63	1.07	0.74 and 1.40
6– 9	0.44	0.11 and 0.77	0.13	-0.20 and 0.46	0.58	0.25 and 0.91
9–13	0.43	0.10 and 0.76	-0.02	-0.35 and 0.31	0.19	-0.14 and 0.52
13–18	0.33	0 and 0.66	-0.03	-0.36 and 0.30	0.08	-0.25 and 0.41

*Obtained from the inequality $d - t_{.05}s < \delta < d + t_{.05}s$, where d is the observed difference, δ the true difference, s and estimate of the "error variance" derived from the 120 degrees of freedom obtained from comparisons between the six samples within groups, and $t_{.05}$ is the 5% significance level of "Student's" t for 120 degrees of freedom. There is 1 chance in 20 that the true value for the difference produced by treatment lies outside the range given.

TABLE 6.—*Increase or decrease in percentage of total soil carbon produced at four depths by unfertilized rotations on the Morrow plats.*

Depth, inches	Corn-oats versus corn		Corn-oats-clover versus corn		Corn-oats-clover versus corn-oats	
	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase or decrease (6 samples), % of sample weight	True value lies between*
0– 6	0.40	0.07 and 0.73	0.54	0.21 and 0.87	0.14	-0.19 and 0.47
6– 9	0.45	0.12 and 0.78	0.63	0.30 and 0.96	0.18	-0.15 and 0.51
9–13	0.56	0.23 and 0.89	0.51	0.18 and 0.84	-0.05	-0.38 and 0.28
13–18	0.59	0.26 and 0.92	0.58	0.25 and 0.91	-0.01	-0.34 and 0.32

*See footnote to Table 5. There is 1 chance in 20 that the true value for the difference produced by the rotations lies outside the range given.

(d) With the fertilized rotations, continuous corn was about equal to the corn-oats rotation in maintaining the total carbon content of the soil at all depths. The corn-oats-clover rotation was much better in this respect than corn or corn-oats, for it maintained total carbon

from 0.6 to 1.26% higher than the other two rotations in the upper 9 inches of soil (Table 7).

TABLE 7.—*Increase or decrease in percentage of total soil carbon produced at four depths by fertilized rotations on the Morrow plats.*

Depth, inches	Corn-oats versus corn		Corn-oats-clover versus corn		Corn-oats-clover versus corn-oats	
	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*	Observed mean increase (6 samples), % of sample weight	True value lies between*
0- 6	0.35	0.02 and 0.68	1.26	0.93 and 1.59	0.91	0.58 and 1.24
6- 9	0.14	-0.19 and 0.47	0.77	0.44 and 1.01	0.63	0.30 and 0.96
9-13	0.11	-0.22 and 0.44	0.27	-0.06 and 0.60	0.16	-0.17 and 0.49
13-18	0.23	-0.10 and 0.56	0.33	0 and 0.66	0.10	-0.23 and 0.43

*See footnote to Table 5.

(e) In the maintenance of total carbon in the 9 to 18 inch depth, there was no significant difference between the three rotations whether fertilized or unfertilized, with the exception of unfertilized, continuous corn which was clearly inferior (Tables 6 and 7).

(f) The total carbon content of the soil usually decreased as the depth increased, the decrease being more rapid at successively greater depths. The differences in total carbon between the 0 to 6, 6 to 9, and 9 to 13 inch depths were not significant except in the fertilized corn-oats-clover plat. The 13 to 18 inch layers averaged 0.37% of the total carbon and were very uniform in all plats.

(g) The average increase observed in total carbon resulting from soil treatment, including all depths and rotations, was 0.323, and, if it is asserted that the true value lies between 0.323±0.165, there is a 1 in 20 chance that this assertion is false. The average content of total carbon of these plats was 1.70% with continuous corn, 2.06% with corn-oats, and 2.31% with the corn-oats-clover rotation. The average content at the various depths was 0 to 6 inches, 2.34%; 6 to 9 inches, 2.26%; 9 to 13 inches, 1.94%; and 13 to 18 inches, 1.56%.

The above results show that for maintaining soil organic matter continuous corn was inferior to corn-oats when no soil treatment was used. With manure, lime, and rock phosphate, however, the continuous corn was practically equal to the corn-oats rotation.

The unfertilized corn-oats-clover rotation had no advantage in organic matter maintenance over corn-oats, but the fertilized corn-oats-clover rotation was much better than the five other combinations of rotation and treatment studied, and appeared to be better

even than bluegrass sod undisturbed for 34 years. This indicates that good management of cultivated soil may be fully as effective in the maintenance of organic matter as a continuous sod crop.

AGGREGATION

Aggregate analyses showed that grass increased the amount of large aggregates greatly (600% over corn or corn-oats) in the upper 6 inches but not below this depth (Tables 8 and 9). Only the best cropping system, namely, corn-oats-clover rotation plus manure, lime, and rock phosphate, was effective in materially increasing the amount of large aggregates in the upper 6 inches of the soil. This fertilizer treatment appeared to increase slightly the amount of aggregates below 0.25 mm in diameter with any cropping system.

TABLE 8.—*Average percentage and range in the percentage of aggregates in six samples from each of the Morrow plats and the adjoining sod at the 0 to 6 inch depth*

Plat	>0.5 mm	Range	0.5–0.25 mm	Range	0.25–0.10 mm	Range	0.10–0.05 mm	Range
C	8.0	14.5–4.0	8.2	11.3–5.9	16.0	18.0–14.2	22.3	25.6–19.1
C+MLP	6.2	7.4–4.9	8.1	9.4–7.1	18.0	20.1–16.1	23.9	27.0–20.9
CO	5.7	7.6–2.9	6.4	6.8–6.2	13.7	14.0–12.3	23.5	25.6–20.8
CO+MLP	7.4	11.5–4.0	8.1	9.8–7.4	16.8	18.6–15.9	24.5	26.5–22.9
COCl	11.0	13.1–9.1	8.4	9.6–7.1	15.3	16.7–14.4	21.9	22.9–19.0
COCl+MLP	13.2	18.3–9.6	13.3	15.1–12.0	20.1	21.0–18.8	19.1	21.9–15.3
Sod	50.0	63.4–44.5	16.9	21.2–12.3	11.9	14.6–6.7	3.5	4.9–1.8

TABLE 9.—*Average percentage of aggregates in six samples from each of three depths on each of the Morrow plats and the adjoining sod.*

Plat	6 to 9-inch depth				9 to 13-inch depth				13 to 18-inch depth			
	0.5 mm	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm	0.5 mm	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm	0.5 mm	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm
C	35.4	15.6	13.9	11.2	34.6	22.3	18.2	8.4	44.5	20.0	15.8	6.1
C+MLP	20.5	14.5	17.4	16.7	23.6	21.8	21.8	12.6	35.3	21.9	18.8	8.2
CO	24.4	14.6	16.2	16.3	26.4	20.2	20.9	11.7	33.1	21.4	18.7	8.8
CO+MLP	22.8	16.5	17.7	15.3	19.5	21.5	23.4	12.4	25.9	23.0	22.0	9.8
COCl	38.4	15.1	13.3	10.2	26.3	20.6	20.5	10.2	28.6	20.5	19.7	10.2
COCl+MLP	20.6	17.5	20.2	16.6	20.4	22.6	23.1	13.7	27.3	23.0	21.7	11.1
Sod	26.9	20.7	19.1	10.2	20.0	18.5	20.7	12.2	24.6	19.7	20.9	10.8

The 6 to 9 inch layer showed little or no difference in aggregation in the C plus MLP, CO, and CO plus MLP plats. The C, COCl, and COCl plus MLP plats were higher in total aggregation than the

other three plats, the C and COCl plats having a high percentage of coarse aggregates. In the lower two depths, namely, 9 to 13 inches and 13 to 18 inches, the continuous corn plat was highest in the largest aggregates (above 0.5 mm in diameter), and also in total aggregation. This is apparently due to the fact that much of the surface soil on this plat has been removed by erosion.

The results show that comparatively large differences in organic matter content may exist without a proportional effect on aggregation or volume weight. Thus, the COCl plus MLP plat in the 0 to 6 inch depth was almost 50% higher than the COCl plat in total carbon, but the differences in aggregation were comparatively minor. This agrees with the findings of Browning (1) and of Puhr and Olson (6). Further, in the 0 to 6 inch depth, the sod border was no higher in total carbon but very much higher in aggregation than the COCl plus MLP plats.

EROSION

The plats growing corn annually were poorly aggregated in the surface but showed increasing amounts of large aggregates with depth. This increase in aggregation with depth is apparently due, however, not to the corn but to erosion which has brought the B horizon 6 to 9 inches nearer the surface under these plats. When this work was begun, it was assumed that little or no soil had been lost from these plats by erosion because of the slight slope (1 to 2%) high organic matter content, and high permeability. In a previous study, Stauffer (9) found that No. 15, a soil similar to this, had an average infiltration of 3.7 inches of water in 1 hour. The occurrence of considerable sheet erosion was later demonstrated, however. The color and appearance of the samples from the continuous corn plats at depths below 9 inches; their comparatively large variations in pH, total carbon, and aggregation; and their high pH values and low carbon content all indicated admixture with materials from the B horizon. Samples from depths of 18 to 30 inches under the COCl and COCl plus MLP plats were similar in aggregation to those below 12 inches under the continuous corn plats.

Careful borings made in the continuous corn plat, unfertilized, showed a transition from the A to the B horizon at approximately 13 inches. In the COCl plus MLP plat, and in the grass border, this transition occurred at 19 to 20 inches. The plats located between the C and COCl plus MLP plats showed a gradual increase in depth from the former to the latter.

A small amount of sheet erosion annually on the continuous corn plats, which are not only kept in an intertilled crop but receive runoff from the other plats, has removed enough soil to bring the B horizon into the 13 to 18 inch zone. This would require the removal of about 6 inches of soil or only 1/10 inch annually since the plats were established, without considering any previous cropping that may have been carried on. The extent of sheet erosion on land of such a slight slope and high degree of permeability is not generally appreciated; nevertheless, losses similar to those estimated above were also found by Conrey and Burrage (2) on Ohio plats of similar slope and good physical condition.

The erosion on the continuous corn plats makes it difficult to compare the soil of these plats with that of the others, particularly at the greater depths where one may be dealing with the B horizon under continuous corn and with the A horizon under the other crops. Thus, a comparatively low content of organic matter in the lower layers of the corn plats may not be due entirely to the corn crop itself but to original differences between the A and B horizons.

PERCOLATION

The results of Stauffer (8) indicate that, on this soil, the percolation of water may be more sensitive to physical changes in the soil than any other measurement so far used. The increased percolation observed by Stauffer in the unfertilized plats at the lower depths is correlated with a large proportion of coarse aggregates in each case. In the plot growing corn continuously, the coarseness of the aggregates is probably due to mixture with the B horizon as discussed above, while in the corn-oats-clover plat, the rotation appears to produce coarse aggregates when manure, lime, and phosphate are not used. In addition, the soil in a part of the corn-oats-clover plat is more sandy than that of any other part of the six plats studied.

SOIL VARIATION

In this investigation each sample from six locations on each plat and from each of four depths was analyzed individually. The variability found in these 1/20 acre plats emphasized the importance of multiple or composite sampling, even on the plats where erosion was least serious (Tables 1 to 5). Although these plats are small and have been carefully handled, considerable variation in pH and total carbon exists in the plow layer of the north and south halves of the fertilized plats (Table 10).

TABLE 10.—*Average pH and total carbon of the three 0 to 6-inch samples taken from the north and from the soil halves of the fertilized plats.*

	C+MLP		CO+MLP		COCL+MLP	
	North	South	North	South	North	South
pH	5.35	5.73	5.80	5.50	5.50	6.88
Total carbon %	2.01	2.16	2.49	2.71	3.00	3.71

It will be noted that the south, or higher half, is more acid in the COCl plus MLP and C plus MLP plats but lower in the CO plus MLP plat, while the total carbon content increases from the lower (north) to the higher (south) sides of each plat. The unfertilized plats not only show no significant variation in the pH of the plow layer, but also practically no variation in total carbon, i.e., 0.07% of the C plat, 0.03% in the CO plat, and 0.25% in the COCl plat, all in favor of the higher (south) half.

SUMMARY

An investigation of the mechanical analysis, volume weight, pH, total carbon, and aggregate analysis of the soil of the Morrow plats was carried out. These plats, established in 1876 and cut down to 1/20 acre in 1904, have been subjected since 1904 to three different cropping systems, namely, continuous corn, a corn-oats rotation, and a corn-oats-clover rotation, with and without manure, lime, and rock phosphate. Samples were taken from each of six locations on each plat and from four depths at each location to 18 inches, and were analyzed individually.

The plats were remarkably uniform in mechanical composition to a depth of 18 inches, with the exception of one location as noted, and fairly uniform in volume weight to a depth of 9 inches.

The limed plats were considerably higher in pH than unlimed plats from 0 to 9 inches but not so much below 9 inches.

The unfertilized continuous corn plat was lowest in total carbon to a depth of 13 inches, whereas the fertilized corn-oats-clover plat was highest to 9 inches. The fertilizer treatment was more effective in lessening the decrease of the carbon content of the soil with continuous corn and corn-oats-clover than with corn-oats. The fertilized corn-oats rotation was not materially better in maintaining organic matter than fertilized continuous corn. The sod border, in bluegrass continuously for 34 years, was no higher in total carbon than the fertilized corn-oats-clover plat.

Grass in the border adjoining the plats exerted the most marked effect on aggregation in the upper 6 inches, with the fertilized corn-oats-clover rotation second.

The soil treatment and the rotations practiced, including continuous grass, even when continued for many years, had little effect on the pH, organic matter content, or aggregation of this soil below a depth of 9 inches.

Examination and analysis of the samples and borings in the field showed considerable erosion had occurred on the plats of lower elevation and on which corn was grown continuously.

Considerable variations in pH and total carbon were observed in the fertilized plats.

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THE MICROFLORA IN THE SOIL AND IN THE RUN-OFF FROM THE SOIL[1]

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PRESENT data indicate that large amounts of the finer particles of the soil are carried away in the water run-off. Literature is lacking on a comparison of the organisms in the soil from which the water came with those in the run-off from the soil. Information is not complete until a clear understanding of the effect which the erosion of the soil has on the micro-organic population is achieved.

Studies have shown that sheet erosion causes a loss primarily of the finer particles of soil which are carried away in the run-off. It is further known that many bacteria are adsorbed on the finer particles. This adsorption was emphasized by Dianowa and Woroshilowa (4)[3] and by Peele (10). Organisms other than bacteria may be affected similarly for Cutler (3) has shown that protozoa were removed from suspensions of soil.

Since most of the organic material is near the surface of the soil and since a large part of the micro-organic population is aerobic and near the surface, it should be suspected that the soil near the surface contains the largest number of the mixed population. Many workers (2) have shown that this condition actually exists. Therefore the conditions are ideal for the organisms to accompany the finer particles when they are carried away by the water. They may be lost either adsorbed with the soil particles or suspended in the run-off. The purpose of this paper, therefore, is to show the extent to which certain physiological groups of the micro-organic population are carried away in the run-off.

EXPERIMENTAL MATERIAL

The samples of soil and the run-off from the soil were collected at the U. S. Dept. of Agriculture Soil Conservation Experiment Station at the Arnot Forest near Ithaca, N. Y. The sampling was started in June 1935 and continued until November of the same year. Further work was resumed May 1, 1936, and suspended in September 1936. The plats are located on the Bath flaggy silt loam soil series, and have a slope of about 20%. Some are on virgin soil and some on soil that has been cultivated for about 70 years. In both cases, in addition to the controls, the plats have received mineral fertilizers and were in a rotation of oats and clover when the samples were collected. By taking samples of the soil of these plats and determining the microflora *in situ* it has been possible to compare the results with those obtained by making similar determinations in the run-off from such plats. In both cases the population is expressed as numbers in a gram of dry material. The samples of soil were analysed within 48 hours and the samples of the run-off within 24 hours. In most instances a much shorter time was required for each than that indicated. The samples consisted of an aliquot of the entire run-offs. They were obtained after stirring the entire quantities.

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication May 17, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 841.

All soils contain certain physiological groups that bring about important changes in the organic and inorganic constituents. No one group, however, appears any more important than any other. For this reason it was considered desirable to make quantitative determinations of several groups, especially of those which are likely to have the largest population. Among these are those that grow on soil-extract agar, ammonifiers, cellulose-decomposers, algae, azofiers, rhizobia and fungi.

The quantitative determinations of the total number of organisms as used in this work were made by counting all colonies that appeared on plates made of soil-extract agar, whereas the total number of fungi was made by counting all colonies resembling fungi that appeared on plates of peptone-glucose-acid agar. To make counts of all other organisms, the dilution method of Hiltner and Stormer (7) was employed. This consisted in taking portions of the soil or the run-off as the inoculum and adding them to a medium that was suitable for the growth of the particular organism in question. The smallest portion of the inoculum which gave growth was taken to represent the number of organisms in that fraction of a gram. From this the number in a gram could be calculated.

The formulae for cellulosic, algal, anaerobic, and agar-media were taken from the manual by Fred and Waksman (5). The aerobic-medium was modified, however, by the addition of a gram or so of sand and 0.25% $NaHSO_3$. The sand probably reduced the circulation of the liquid containing oxygen while the $NaHSO_3$ evidently lowered the oxidation-reduction potential.

The presence of ammonifiers, ammonia and sulfur oxidizers were detected by the presence of their end products, following the procedures described by Hansen (6), Wilson (11), and Brown (1), respectively. Nodule formation on the roots of red clover (*Trefolium frateuse*), alfalfa (*Medicago sativa*), and vetch (*Vicia villosa*) indicated the presence of their respective rhizobium. The culture tubes containing the anaerobic medium were incubated 14 days, then heated for 10 minutes to 80° C and some of the material transferred to a fresh tube containing a medium of similar composition. The presence of the organism was noted when gas was observed upon further incubation for a period of 5 days. The length of the incubation was varied to meet the growth requirements of the particular group of organisms. Cultures for the presence of algae were placed in light and the number of cellulose-destroying-organisms detected by their disintegrating action on strips of filter paper. Sulfanilic acid and alpha-napthyl-amine in acetic acid were used to detect the formation of nitrites from ammonia. Directions for these tests may be found in the manual by Fred and Waksman (5). Total solids in the run-offs were obtained by evaporating large volumes of the run-offs and weighing the residues.

PRESENTATION OF DATA

It is presumed that the micro-organic population found in the run-off from the soil came from the soil. No tests were made of the rainfall to show what kind or how many organisms it might have contained. Marshall (8) reports an average of only 3.5 in each ml. Micro-organisms in addition to the soil particles should be expected in the run-off, for the work of Peele (10) and others showed that many bacteria may be adsorbed on the particles of soil. In 1935 and 1936 many data were obtained bearing on the population in the soils of the various plats and in the run-offs from the soils. Since the findings are similar in many ways only those will be given in detail which illustrate the findings.

In Table 1 are given the results of 12 determinations of the micro-organic population which was obtained between June 17 and November 3. The table also shows the population in the run-offs after five rains. It is evident that for each gram of solid material there were many more organisms in the run-off than there were in the soil from which the run-off came. The numbers as determined by the agar plate method showed at no time more than 21 million in each gram of soil. In most cases it was less than one-half this number. The numbers in the run-off from this plat following five rains exceeded the numbers found in the soil in every instance. The average number as ascertained by six determinations before the rain was less than 5 million, and 5 days before the rain on August 13 the number was less than 10 million. In the run-off after 0.4 inch of rainfall on this date, however, there were 10,871 million. If the dilution counts of such groups of organisms as the ammonifiers, ammonium oxidizers, anaerobes, and those of other physiological groups are considered, the results are similar to the above although the numbers are much smaller.

The micro-organic population in the soil of a virgin, unfertilized plat and that in the run-off from the same plat are shown in Table 2. A larger number in the run-off is evident. It resembles that found in the run-off from the cultivated soil shown in Table 1, and the same type of comparisons between the population in the soil and in the run-off could be made.

Of equal interest are the summary results from the samples of soil and from the samples of the run-offs from the soil during the period of June 17 to November 3. During this period 12 determinations were made of the population in the soil of eight plats and 5 in the run-offs after rains. Plat A-5 was growing corn and had received 200 pounds of a 5-10-15 fertilizer annually. Plat A-6, also in corn, was unfertilized and A-8 was fallow. A-11 was cropped in a rotation of oats, clover, and corn with 300 pounds of superphosphate, 2,000 pounds of limestone before oats, 6 tons of manure, and 300 pounds of superphosphate before corn. E-1, in a rotation of oats, clover, and corn, was strip-cropped, and unfertilized. E-2, in a rotation of oats, clover, and corn, was unfertilized but cultivated up and down the slope. (See Table 4.) Plat E-3, in a rotation of oats, clover, and corn, was fertilized with 300 pounds of superphosphate, 2,000 pounds of limestone before oats, 6 tons of manure, and 300 pounds of superphosphate before corn.

The rainfall and the run-off, together with the quantity of solids in the run-off from June 8 to October 29, 1935, for two plats, are shown in Table 3. The loss of water and solids in the run-off from eight plats after 1.4 inches of rainfall on June 18, 1936, which occurred in about 10 minutes, are shown in Table 4. The data on the population in the soil and in the run-off from May through October 1936 are shown in Table 5.

It appears from the agar plate count and from the determination of the number of organisms of the various physiological groups that there were in several instances 180 to 400 times as many organisms in the run-off for each gram of solid material as there were in the soil from which the run-off came.

TABLE 1.—*Number of organisms in the unfertilized and cultivated soil and in the run-off from the soil, Plat A II, 1935.**

Number determined by	Source of sample and date																
	Soil												Run-off				
	June 17	July 3	July 17	July 24	July 30	Aug. 8	Aug 21	Aug. 31	Sept. 12	Sept. 24	Oct. 10	Nov. 3	July 8	July 13	Aug. 27	Oct. 23	Oct. 29
Agar-plate†	6	3	6	3	2	9	21	6	4	2	6	20	48	10,871	720	169	85
Dilution count:																	
In peptone broth†	1	1	10	1	1	1	10	1	10	1	1	10	91	580	312	4	—
Ammonifiers†	0.1	1	10	0.1	1	1	10	0.1	1	1	1	1	91	560	312	4	—
S-oxidizers‡	0.01	0.01	0.05	0.05	0.01	0.01	0.05	0.1	0.1	0.1	0.05	0 5	0.1	0.05	0.15	0.47	—
Nitrifiers‡	1	1	1	1	1	1	10	5	5	5	10	10	23	56	76	4	—
Anaerobes‡	—	0.1	0.1	0.1	0.01	0.1	1	0.01	25	0.1	0.1	0.1	—	5	0.3	0.5	—
Cellulose‡	0.01	0.1	0.1	0.1	0.1	1	1	0.1	1	1	1	1	0 09	58	27	12	—
Rhizobia trifolii	1	10	1	1	1	0	100	100	10	10	100	10	1	58	3	3	—
Fungi§	14	12	9	14	13	9	10	17	11	9	19	30	145	3,645	1,400	761	110
Algae‡	0.25	0.01	0.05	0.5	0.5	0.5	0.5	1	1	0.5	1	10	0.22	0.29	78	4.7	—
Rainfall, inches	—	—	—	—	—	—	—	—	—	—	—	—	0.91	0.40	1.02	0.47	1.63
Water loss, inches	—	—	—	—	—	—	—	—	—	—	—	—	0.166	0.009	0.067	0.004	0.016
Water loss, tons per acre	—	—	—	—	—	—	—	—	—	—	—	—	18.77	2.03	7.57	0.45	1.80
Soil loss, lbs. per acre	—	—	—	—	—	—	—	—	—	—	—	—	240	4	48	2	4

*Plat size 72.6 feet long, 6 feet wide.
†Multiply by 1,000,000.
‡Multiply by 1,000.
§Multiply by 10,000.

TABLE 2.—*Number of organisms in the virgin, fertilized soil and in the run-off from the soil, 1935.**

Number determined by	Source of sample and date																	
	Soil													Run-off				
	June 6	June 17	July 13	July 17	July 24	July 30	Aug. 8	Aug. 21	Aug. 31	Sept. 12	Sept. 24	Oct. 10	Nov. 3	July 8	Aug. 13	Aug. 27	Sept. 23	Sept. 29
Agar plate†	1	9	3	1	4	1	11	7	14	3	3	3	3	23	11,053	6,925	77	600
Dilution count:																		
In peptone broth†	1	1	1	10	10	10	10	1	1	10	1	1	1	14	454	3,120	45	—
Ammonifiers‡	1	1	10	1	0.1	10	10	10	10	1	10	10	10	10	454	31,200	450	—
S-oxidizers§	0.1	0.1	0.1	0.5	0.1	0.1	1	0.1	1	10	0.5	0.1	0.5	1.4	4.5	3.6	2.3	—
Nitrifiers§	10	10	10	10	50	10	10	100	100	250	250	250	100	142	23	714	450	—
Anaerobes§	0.01	—	1	1	0.1	1	1	1	1	10	1	1	1	—	45	71	400	—
Cellulose§	1	1	0.1	1	1	1	1	1	1	10	10	1	1	1	45	92	1,130	—
Rhizobium trifolii§	0.01	0.01	0.01	0	0.01	0.01	0.01	0.1	0.1	10	10	1	1	0.01	0.05	0.07	0.04	—
Fungi‡	2.3	3.2	4.3	2.2	0.21	1.8	2.7	2.1	3.3	2.3	2.4	1.6	2.2	10	20	2.170	90	16
Algae**	0.025	0.010	0.025	0.100	0.100	0.050	0.05	0.025	0.10	1	0.050	0.10	5	0.025	0.227	17.8	27.0	—
Rainfall, inches	—	—	—	—	—	—	—	—	—	—	—	—	—	3.46	0.40	1.02	0.47	1.63
Water loss, tons per acre	—	—	—	—	—	—	—	—	—	—	—	—	—	17.19	0.113	4.75	1.01	1.13
Soil loss, lbs. per acre	—	—	—	—	—	—	—	—	—	—	—	—	—	194	1	16	5	1

*Plat size 132 feet long, 33 feet wide.
†Multiply by 1,000,000.
‡Multiply by 100,000.
§Multiply by 100.
**Multiply by 10,000.

TABLE 3.—*Rainfall and quantity of run-off with solids in the run-off (acre basis), 1935.*

Date	Rainfall, inches	Run-off			
		Plat A5, corn		Plat E2, corn-oats	
		Water in tons	Solids in pounds	Water in tons	Solids in pounds
July 8	2.89	326.89	6,210	25.56	1,400
Aug. 13	0.40	2.48	51	3.73	78
Aug. 27	1.02	19.68	473	18.41	370
Oct. 23	0.47	2.26	46	2.94	18
Oct. 29	1.63	9.95	86	5.09	9

TABLE 4.—*Loss of water and solids in the run-off following 1.4 inches of rainfall, June 18, 1936.*

Plat*	Crops	Cultivation	Run-offs	
			Water, tons per acre	Solids, lbs. per acre
A 3	Corn	Level	75.10	7,586
A 6	Corn	Level	73.06	7,722
A 8	Fallow	Level	80.30	17,141
A 11	Clover	Level	1.47	13
A 13	Clover	Level	1.80	23
E 1	Strip crop corn, oats, clover	Strip	22.05	1,406
E 2	Up and down corn, oats, clover	With slope	20.47	2,849
E 3	Corn, oats, clover	Strip cropped	12.78	469

*A plats 72.6 feet long and 6 feet wide; E plats 132 feet long and 33 feet wide. Duration of rain 10 minutes.

During this study numerous determinations were made of the population in the soil and in the run-off which are not shown in previous tables. The results are so much like those already presented and so voluminous that their presentation in detail seems scarcely necessary. All the data obtained, however, have been arranged in Table 6. In this table all the plats are represented, whether fallow, in rotation, variously fertilized, virgin, strip-cropped, or cultivated up and down the slope. Within the two seasons 108 determinations were made of the population in the soil and 68 in the run-offs from the soil of the same plats. The method by which the various micro-organisms were ascertained are indicated in the table. Those organisms in the soil as ascertained by the agar plate method in 1935 totalled about 6.5 millions in a gram while those in the run-off totalled about 2,046 millions. In 1936, the organisms in the soil as ascertained by the same method totalled about 7.3 millions in a gram, while those in the run-off totalled about 1,625 millions. The population of the various physiological groups as ascertained by the dilution

TABLE 5.—*Summary data of population in the soil and in the run-off from the soil, May through October, 1936.**

Number determined by	Source of samples amd plat numbers															
	Soil								Run-off							
	A5	A6	A8	A11	A13	E1	E2	E3	A5	A6	A8	A11	A13	E1	E2	E3
Agar count†	5	7	3	8	9	10	7	9	906	985	708	2.241	3.662	2.242	1.264	976
Dilution counts:																
In peptone broth†	0.9	0.9	0.9	3	3	4	2	4	713	559	167	883	339	141	896	253
Ammonifiers†	0.9	0.7	0.7	3	3	3	2	4	713	559	466	133	339	141	790	253
S oxidizers‡	0.05	0.15	0.06	0.08	0.05	0.05	0.1	0.06	19	2	8	0.9	0.9	2	11	1
Nitrifiers‡	6	4	3	5	6	7	8	9	10	9	49	15	7	22	40	32
Anaerobes‡	2	4	5	8	6	2	3	2	38	107	36	5	1	4	33	844
Cellulose‡	0.4	0.6	2	0.6	0.5	2	2	0.7	177	3	2	224	90	133	335	43
Rhizobium trifolii‡	0.03	2	0.005	0.05	4	2	2	4	0.09	0.3	0.02	0.8	0.05	0.2	0.07	0.6
Fungi†	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	5	71	15	18	32	22	54	9
Algae‡	2	2	0.3	0.6	0.8	4	2	20	875	53	247	456	110	319	2,471	484
Water run-off, inches									0.99	1.242	2.68	0.05	0.075	0.302	0.336	0.211
Water run-off, tons per acre									11.2	130.9	353.13	5.65	6.44	34.15	18.0	23.86
Solids lost, lbs. per acre									8,546	7,973	30,179	18	35	1,623	3,653	67

*Average of seven samples from both sources.
†Multiply by 1,000,000.
‡Multiply by 1,000.

method was of the same order, with one exception, though perhaps less pronounced. There appeared to be no more *Rhizobium trifolii* in the run-off than was found in the soil.

TABLE 6.—*Total number of organisms in the soil and in the run-off from the soil for all plats, two seasons, 56 determinations.*

Number determined by	1935		1936	
	Soil	Run-off	Soil	Run-off
Agar plate	6,503,890	2,046,381,120	7,394,458	1,625,861,730
Dilution method:				
In peptone broth	7,004,807	611,285,000	2,633,920	493,630,000
Ammonifiers	2,085,480	574,230,370	2,285,700	424,107,700
Ammonia oxidizers	7,935	38,284	6,222	23,000
Sulfur oxidizers	74	325	79	4,543
Anaerobes	762	6,574	3,961	133,700
Cellulose bacteria	875	17,102	1,030	125,160
Rhizobium trifolii	106	11	1,587	191
Fungi	189,297	9,196,970	201,370	28,266,650
Algae	2,591	55,512	3,967	587,158

Attempts were made to compare the number of organisms in the run-off from the virgin soil with those in the run-off from the cultivated soil. Also, information of a similar nature was sought from plats to which different mineral fertilizers were applied. The data for making the comparisons were so much alike that it was difficult to conclude that the quality or the quantity of the population in the run-off was in any way strikingly dissimilar due to fertilization. The run-off from certain unfertilized plats, however, appeared to carry more fungi, algae, anaerobes, and cellulose-destroying bacteria for each gram of solids in the run-off than did the run-off from fertilized plats, the crops in both cases being the same.

DISCUSSION

In this work no attempt was made to obtain a mechanical analysis of the solids in the run-off. It was suspected that light rains would produce a run-off carrying a high proportion of the finer material, while heavy rains would produce a run-off carrying a sediment more nearly like that of the whole soil. The work of Middleton, *et al.* (9) shows this to be the case. A mechanical analysis, therefore, of the solids in the run-off might explain why the run-off contained a higher population for each gram of solids than was found in the soil from which the run-off came. This should mean that soil with 100% cover would lose a large portion of the fine particles and thus a larger population of the flora than would be the case if a soil were not so well covered. This may explain why the data in certain cases indicated a larger population in a gram of material in the run-off from plats growing crops than was obtained in the run-off from the uncropped plats.

The suggestion by Middleton, *et al.*, was substantiated by these population studies. Total numbers as determined by the agar plate

method showed in the soil before a rainfall of 3.46 inches 1 million organisms in a gram, while in the run-off there were 23 million. In another case, when the rainfall was only 0.4 inch, the population in the soil was about 9 million and in the run-off about 11,053 million. In still another case, before a rainfall of 1.02 inches the population was about 7 million while that in the run-off was about 6,925 million. Such wide differences, however, were not always so regular with total number of fungi.

CONCLUSIONS

The quality and the quantity of the microflora in the soil of the plats and in the run-off from these soils were determined. The counts of the organisms of the various physiological groups were expressed as numbers in each gram of solids. By averaging the data, all determinations show that the total number in the run-off exceeded that in the original soil about 200 times.

The number of ammonia and sulfur oxidizers, of *Rhizobium trifolii*, and of anaerobes that were found in the soil or in the run-off from the soil constituted a small fraction of the total population.

Under the conditions of these tests fertilizers did not affect the number of organisms in the sample of the original soil or in the run-off obtained from the soil.

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SOIL ORGANIC MATTER AND NITROGEN AS INFLUENCED BY GREEN MANURE CROP MANAGEMENT ON NORFOLK COARSE SAND[1]

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THE organic matter of soils is commonly considered to have two functions that bear on soil fertility. One is essentially physical and consists in maintaining soil tilth, holding moisture, and retaining plant nutrients either in an exchangeable form as reported by McGeorge (8, 9)[3] and others, or combined in a less available form as part of the humus body. The other function occurs during the decomposition process and results in the liberation of the combined nitrogen and other nutrients. The retentive function may be comparatively lasting, but the second is temporary and for a given unit of soil organic matter can occur but once. As the rate of decomposition is largely determined by such conditions as temperature, moisture, and aeration which regulate biological activity and since these conditions are favorable in the southeastern states, it follows that the main problems associated with green manuring in this region are to maintain adequate reserves of organic matter by renewal and to regulate the decomposition so that it is of maximum benefit to succeeding crops.

Regional comparisons by Hester and Shelton (3) have correlated the loss of organic matter with annual mean temperatures, while Jenny (5) has concluded that it is difficult to build up organic matter and nitrogen reserves in these warmer regions. The extent of organic matter losses under Sandhill conditions is indicated by lysimeter studies in which more than 50 pounds of nitrogen per acre, equivalent to about 300 pounds of sodium nitrate, leached through a 43-inch profile of fallow Norfolk coarse sand in one winter season after turning under a 7-ton crop of *Crotalaria striata*. Other studies (12) have shown that 77% of the carbon in soybean tops and 90% of the carbon in corn stover was lost from the soil by decomposition within 14 months after application at the rate of 200 tons of fresh material per acre.

FIELD PLOT EXPERIMENTS

This paper summarizes the results of field experiments which were planned to measure the effect of different crop managements on the carbon and nitrogen content of Norfolk coarse sand. The purpose of the work was to obtain information on (a) changes in carbon and nitrogen content of the soil during three cycles of a rotation of le-

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[3]Numbers in parenthesis refer to "Literature Cited", p. 852.

gumes, corn (*Zea mays*), and cotton (*Gossypium hirsutum*) under different fertilizer treatments and different winter management; (b) the quantity of organic matter added to the soil by the whole plant and by the stubble and roots of certain legumes; and (c) the stimulation of succeeding crop growth by the various green manuring treatments.

The rotation experiment consisted of growing legumes, corn, and cotton in replicated field plots on Norfolk coarse sand at the Sandhill Experiment Station, Columbia, S. C., from 1929 to 1937. The details of the experimental outline and some of the results of the first two rotations have already been described (1, 2, 10, 11). The legumes used in the different plots were soybeans (*Soja max*), velvet beans (*Stizolobium deeringianum*), and cowpeas (*Vigna sinensis*). These were turned under as green manure and followed by corn the first year and cotton the second year, which were fertilized with 400 and 800 pounds per acre, respectively, of a 2–8–4 ($N-P_2O_5-K_2O$) fertilizer. On an adjacent series of plots the same kinds of legumes were removed as hay and the stubble was turned. The corn and cotton on these plots were fertilized with a 6–8–4 mixture at the rate of 400 and 800 pounds per acre, respectively. The legumes turned under as green manure were fertilized with 400 pounds per acre of a 2–8–4 mixture and those removed for hay received 400 pounds of a 6–8–4 fertilizer.

The experiment also included a series of plots on which a winter cover crop of rye (*Secale cereale*) was planted in the fall following cowpeas, thus providing a cover crop on the area one winter in three.[4] The rye was not fertilized. Samples of soil were collected from the surface horizon of each plot in the spring and fall and were analyzed for carbon and nitrogen.

RESULTS OF THE FIELD EXPERIMENTS

The annual changes in soil carbon and nitrogen of the plots where cowpeas, soybeans, and velvet beans were grown and turned under as green manure in rotation with cotton and corn are shown in Fig. 1. There was a decrease in carbon content of the soil during the course of the experiment. This decrease was greatest during the first 2 years.

The change in average nitrogen content of the soil was small, but there were comparatively large semi-annual changes in nitrogen during the last 3 years, the values in all treatments being lower in the spring than in the fall. It seems likely there was a fixation of nitrogen in the soil during the summer and a liberation, possibly by conversion to nitrate and subsequent leaching, during the winter, but it is not known why this effect should have become so marked during the last 3 years and was not apparent during the early part of the experiment. During this last 3-year period, crop yields were low. Since the carbon decreased and the average nitrogen content did not change appreciably, there was a decrease in the carbon-nitrogen ratio of the soil under all three legumes from about 26:1 to about 17:1. No beneficial effects on soil fertility, as indicated by crop yields, accompanied this decrease in carbon-nitrogen ratio.

[4]Vetch and rye planted but negligible amounts of vetch were obtained.

If any of the three legumes had had more effect on the soil organic matter than the others, it should have been cumulative during the 9-year period and a divergence of the data represented in Fig. 1 would have appeared. However, the curves representing the soil composition from each of the legume treatments do not show any consistent trends, which indicates that there was no outstanding difference in the effects of cowpeas, soybeans, and velvet beans used as green manure on this soil, although the values for soil nitrogen are slightly lower and resultant carbon-nitrogen ratios slightly greater in the cowpea plots during the second to seventh year of the experiment.

The data of Fig. 1 were obtained from average values of the plots during the rotation and thus each point on the curve is an average value of soil which had been cropped to the indicated legume, corn, and cotton. This procedure would have shown any cumulative effect but might have masked any short time influence of these crops when considered separately.

Fig. 2 was obtained by averaging the data with respect to the crop grown, thus yielding a curve each point on which represents an average value for 9 years under the indicated crop. No marked changes in

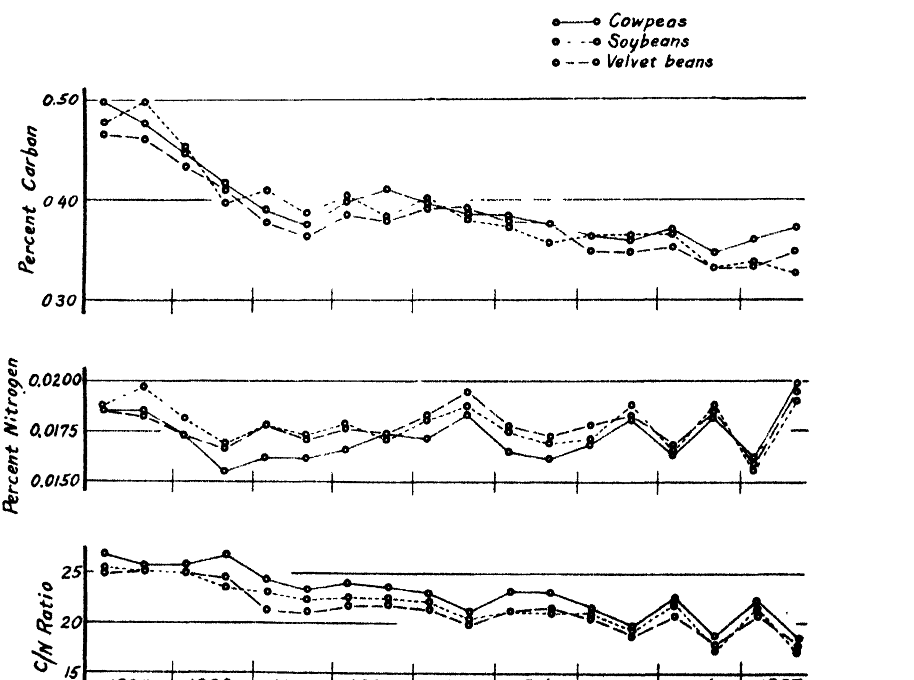

FIG. 1.—Comparative effect of cowpeas, soybeans, and velvet beans used as green manures in a 3-year legume-corn-cotton rotation on the carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand. The points, charted each year, give the average soil analyses in spring and fall, respectively.

soil composition can, with certainty, be ascribed to the growth of the different crops except that the somewhat lower nitrogen values and higher carbon-nitrogen ratios for cowpea plots are apparent.

The experiment provided for the comparison of two crop management systems, *viz.*, turning the entire legume as a green manure with use of a low-nitrogen fertilizer on the following corn and cotton, and removal of the legume as hay with use of a high-nitrogen fertilizer on the following corn and cotton. The changes in soil carbon and nitrogen from these treatments were similar for each of the legumes. The data for all three legume treatments were therefore averaged and these average results for the two systems are given in Fig. 3. The curves indicate that turning under the whole plant and use of a 2–8–4 fertilizer did not increase either the permanent soil carbon or nitrogen compared with the quantity present when only the stubbles were turned and the crops were fertilized with a 6–8–4 mixture. In fact, the trends in Fig. 3 indicate that turning under the entire plant resulted in a slightly lower carbon and nitrogen content of the soil than turning under the legume stubble. The carbon-nitrogen ratio of the soil resulting from the two systems was similar.

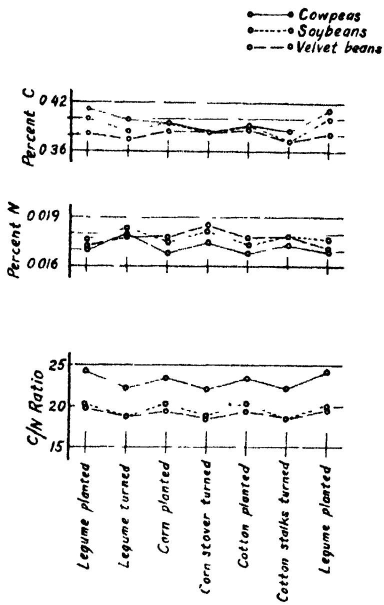

FIG 2.—Comparative effect of cowpeas, soybeans, and velvet beans, each in rotation with corn and cotton, on the carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand. Average of 9 years. "Crops planted" indicate soil analyses in the spring at planting time, and "crops turned" indicate analyses at time crops were turned under in the fall.

A comparison of cowpeas followed by a winter cover crop of rye versus cowpeas followed by winter fallow was provided in one series of plots. It is apparent from Fig. 4 that a winter cover crop of rye once in 3 years maintained the carbon and nitrogen at a higher level than comparably managed plots that were continuously winter fallowed. The carbon-nitrogen ratio of the soil in the winter rye plots was similar to that in the soil of the winter fallow plots, indicating a possible similarity in the chemical composition of the soil organic matter in both cases and merely a change in the quantity present, rather than a difference in its chemical composition.

Crop yields were determined during the experiment. These varied from year to year. The yield of green vegetation was converted to relative yields, taking the yield on the cowpea-winter fallow plot of each fertilizer management each year as unity. There was a con-

siderable degree of association between the yield of crops and the soil carbon and nitrogen data. Soybean and velvet bean yields during the 9-year period averaged 94% and 157%, respectively, of the cowpea yields on those areas where the crop was removed as hay and the stubble only was turned. Corresponding figures for soybeans and velvet beans on the plots where the entire crop was turned under were 90% and 145% of the cowpea yields, respectively. From con-

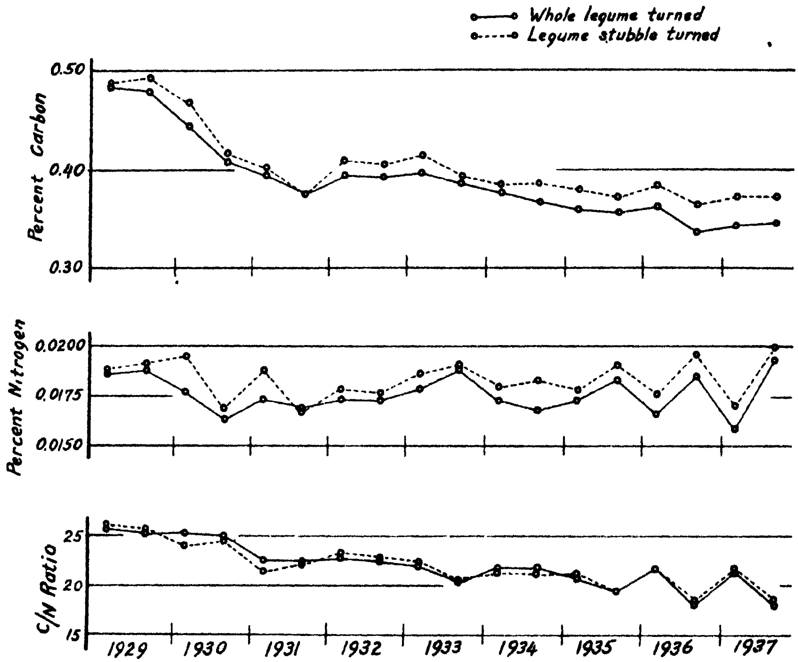

FIG. 3.—Comparative effect on the carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand of turning under whole legumes versus removal of the legumes as hay and turning the stubble, during a 3-year rotation of legumes, corn, and cotton. Points charted each year represent average soil analyses of samples taken in the spring and fall, respectively.

sideration of the individual data, it is believed that the difference between the soybean and the velvet bean yields were significant but that the differences between the cowpea and soybean yields were not significant.

The average yields of corn and cotton following soybeans and velvet beans were 114% and 98%, respectively, of those following cowpeas where the hay was removed and stubble only turned under, and 116% and 100%, respectively, where the whole plant was turned as green manure. Thus, soybeans used as a green manure produced slightly larger yields of following corn and cotton than cowpeas or velvet beans, which appeared to be about equally effective as green manure crops under the conditions of this experiment. Therefore, the greater

tonnage of velvet bean green manure turned under was no more beneficial than cowpeas and less effective than soybeans in stimulating the growth of the corn and cotton which followed. Where rye was used as a winter cover following cowpeas, the average yield of corn and cotton was increased over the winter-fallow treatments by 35% on the plots where the cowpea hay was removed and stubble turned and 46% on the plots where the cowpeas were turned as

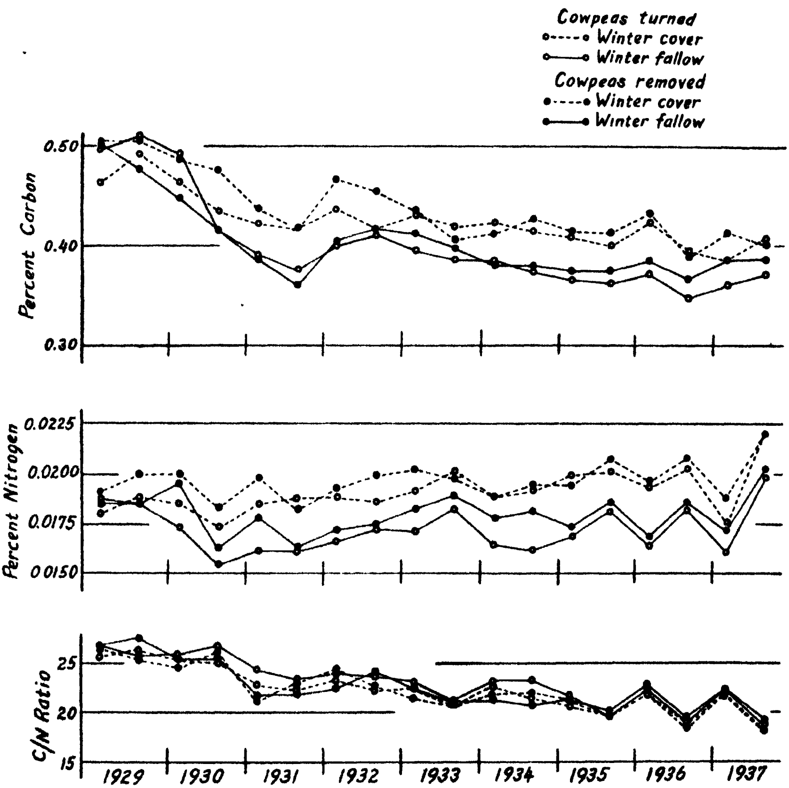

FIG. 4.—Effect on the carbon and nitrogen content and the carbon-nitrogen ratio of winter rye and winter fallow following turning of cowpeas as green manure and cowpea stubble during a 3-year rotation of cowpeas, corn, and cotton. Points charted indicate average soil analyses of samples taken each year in the spring and fall, respectively.

green manure. These differences between winter fallow and winter rye management were in the same direction in 35 of the 36 possible comparisons.

LYSIMETER EXPERIMENTS

In addition to the field experiment discussed above, green manuring experiments were conducted in lysimeters during a 5-year period for the purpose of observing the relationships between leaching, soil

composition, and crop growth. The lysimeters contained a 43-inch profile of virgin Norfolk coarse sand and were 0.0005 acre in area. *Crotalaria striata* and cowpeas were grown as green manure crops in 1933 and 1934 to establish soil fertility differences and an indicator crop of pearl millet (*Pennisetum glaucum*) was grown from 1935 to 1937 to measure these differences agronomically. Winter rye followed the legume in one pair of tanks, while the other pair were winter fallowed. The pearl millet was cut for hay and all the tanks were winter fallowed during the indicator crop period. The legumes and pearl millet were fertilized with a 4-8-4 mixture at the rate of 400 pounds per acre. One lysimeter was maintained continuously fallow and similarly fertilized as a control

Fig. 5 compares the effect on the soil carbon and nitrogen of the two green manure crops. In general, there was no important or highly significant change in carbon during the 2 years that legumes were grown but considerable change occurred during the succeeding 3 years of the indicator crop period There was a loss of carbon in the uncropped control tank except in the spring of 1936 There was no significant change in carbon where the crotalaria or cowpeas were turned under in absence of a winter cover, but a definite increase where crotalaria was turned and followed by winter rye. There was a slight loss of nitrogen from the control tank. The nitrogen of the cropped tanks increased, particularly in the crotalaria tanks The increase was greater where winter cover was used than under winter fallow management. This increase was small while the tanks were cropped to legumes, but, particularly in the case of the crotalaria, increased markedly after the tanks were cropped to pearl millet.

The combined carbon and nitrogen effects are reflected in the carbon-nitrogen ratio, which decreased slightly in the cowpea tank and decreased appreciably in the crotalaria tanks, the lower C/N ratios in general being associated with the winter cover management. This change occurred during the period when legumes were grown, and remained constant later when the tanks were cropped to pearl millet, indicating a change in the composition of organic matter resulting from growing these crops. The carbon-nitrogen ratio of the fallow tank increased from spring to fall in 1936, 1937, and 1938 in a manner similar to the field experiment, the average value remaining constant throughout the experiment. This seasonal fluctuation was not noted in the cropped tanks.

The yield of crotalaria and cowpeas was somewhat similar in 1933 and in each case was the same on the tanks which were to receive a winter cover and a fallow management. Crotalaria yields were more than double cowpea yields in 1934, and were increased slightly by the rye crop planted in the fall of 1933 and turned in the spring of 1934. An excellent crop of pearl millet was obtained in 1935. The yield of pearl millet following crotalaria was considerably greater than that following cowpeas and was materially improved by turning winter rye. The pearl millet crops in 1936 and 1937 were much smaller but still showed the benefit of the winter cover crops planted in 1933 and 1934 and gave larger yields following crotalaria than following cowpeas.

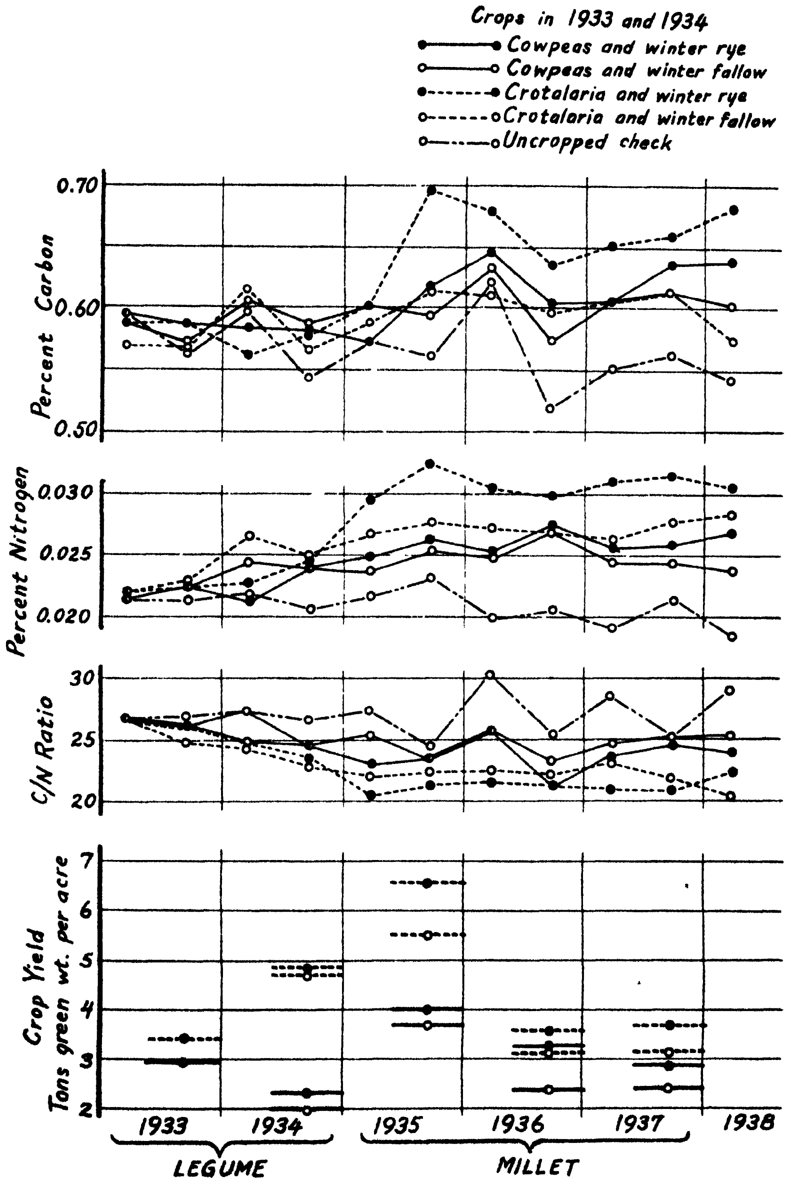

FIG. 5.—Effect of growing and turning under cowpeas and *Crotalaria striata* as green manures, with and without winter rye, on the soil carbon and nitrogen content and the carbon-nitrogen ratio of Norfolk coarse sand in lysimeters and on the yield of following crops of pearl millet.

DISCUSSION

There has been a large amount of research devoted to green manuring and the decomposition of organic residues in the soil. The agronomic phases up to 1926 have been ably reviewed by Pieters (15). In general, it seems clearly established that green manures improve the yield of following crops on nearly all soils where moisture is not a limiting factor, the percentage increases being larger as the inherent fertility of the soil is less. Legumes are generally considered superior to non-legumes for soil improvement purposes.

Lyon (6, 7) and others have shown that the effectiveness of green manures is not entirely a matter of quantity, but there are specific, although unknown, qualitative effects which make some plant species superior to others under different conditions and for various following crops. It seems to be generally accepted that green manures of any kind increase the content of soil organic matter, although the extent of such increase may be materially influenced by various conditions, such as liming (13, 14).

Since increased crop yields and gains in soil organic matter both result from green manuring, it would appear that the increased yield of the following crop is a result of the increase in soil organic matter and that there might be some direct relationship between the two. However, there is little published data which directly applies to such a theory. These experiments on Norfolk coarse sand show that under winter fallow conditions the following crop yields were not proportional to the amount of green manure turned and that measurable increases in soil organic matter were not followed by greater crop yields. It was also found in the field experiment that removal of the above-ground portion of legumes receiving a 6–8–4 fertilizer and turning only the root and stubble portions resulted in more, rather than less, soil carbon and nitrogen than was obtained by turning the entire legume fertilized with a 2–8–4 mixture. The difference in fertilizer used in the field experiments probably does not explain the observed differences since similar results were obtained in the lysimeter under uniform fertilizer management.

Rye as a winter cover following summer legumes in a rotation of corn and cotton slowed down the loss of carbon and prevented the depletion of soil nitrogen as compared with the same rotation where winter rye was omitted. Except for the cultivation of winter rye, the chief difference among the various treatments was the use of roots and stubbles as a source of soil organic matter in some of the treatments in contrast to the use of the entire plant in the others. The data show that where roots and stubble were turned, both soil carbon and soil nitrogen were maintained at a higher level than where the legume tops were also incorporated in the soil. Legumes tops are rich in nitrogen, calcium, and other nutrients compared with legume roots and stubble. The tops decomposed rapidly after turning, releasing their contained nutrients and stimulating microbiological activity to such an extent that nearly all the added material and also more or less of the original soil organic matter was decomposed. In contrast, the more woody and less readily decomposable root and stubble portions did not stimulate microbiological activity to the same extent

as the tops, consequently the decomposition that occurred extended over a much longer period during which there was apparently time for the observed fixation of nitrogen.

The data indicate that under the conditions of these experiments, non-legumes and particularly roots and stubbles were more effective than whole legumes in maintaining both the carbon and nitrogen content of the soil and consequently were more efficient in building up the supply of organic matter, but there is no evidence that the increase of organic matter thus established is in itself beneficial to the growth of the following crops. In the lysimeter experiment, the large increases of soil carbon and nitrogen in 1935 were followed by reduced yields of millet in 1936. The data show that increased yields of following crops occurred where the greatest amount of added organic matter decomposed. From this, it appears that the decomposition of organic matter with the release of its contained nutrients is the function that stimulates crop growth and that the chief benefits of green manuring are obtained when conditions are established for its destruction by decomposition processes.

These experiments did not provide data for the comparison of rye with legumes as a source of soil organic matter, although the combination of rye and legumes resulted in higher fertility and more organic matter in the soil than use of legumes alone. Unpublished lysimeter experiments have shown that in addition to the benefits resulting from the organic matter turned into the soil when the winter cover crop is plowed under, rye also conserves the nutrients released during the decomposition of the green manures turned under in the fall. This is important under Sandhill conditions as the decomposition of succulent material turned under in the fall is largely completed during the winter before spring crops are planted and under fallow conditions the nutrients would be released and leached from the soil before they could be utilized by the following summer crop. A winter cover crop of rye absorbs these nutrients and holds them during the winter, as shown by Hill (4). When it is plowed under in the spring and allowed to decompose, these nutrients are released at the time they are of benefit to the summer crop.

SUMMARY

Changes in the carbon and nitrogen content of Norfolk coarse sand resulting from the growth of different green manure crops were determined semi-annually. Soybeans and velvet beans used as green manures in field plots in a 3-year rotation of legumes, corn and cotton were generally similar in their effects. The soil of the cowpea plots was a little lower in nitrogen and had a higher carbon-nitrogen ratio. Soil carbon and nitrogen were lower when the entire legume, fertilized with a 2% nitrogen mixture, was plowed under than when the legume stubble grown with a 6% nitrogen mixture was turned. A summer green manure crop followed by a winter cover crop of rye maintained the soil carbon and nitrogen at a higher level than a summer cover crop with winter fallow management. Cotton and corn yields were improved following the use of leguminous green manures in summer followed by winter rye.

Crotalaria striata and cowpeas, with and without a winter cover crop of rye, were grown 2 years in lysimeters. These were followed by pearl millet without a winter cover crop for 3 years. A marked increase in soil carbon and nitrogen occurred in the crotalaria tanks after they were planted to pearl millet. Pearl millet yields were greater following crotalaria than following cowpeas and were increased by a winter cover crop of rye compared with winter fallow.

The results indicate that maximum benefits of green manuring are obtained by storing organic matter with its contained nutrients during the soil improvement period and then releasing the nutrients by decomposition of the organic matter at the time they are of most benefit to the following crop. On porous soils, winter cover crops are needed to hold the nutrients released by the decomposition of a summer green manure until the next season's crop can utilize them.

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SOME FACTORS WHICH INFLUENCE INFILTRATION AND ITS MEASUREMENT IN HOUSTON BLACK CLAY[1]

C. W. LAURITZEN AND NORVAL L. STOLTENBERG[2]

INFILTRATION has received added consideration recently due to the importance of this process as it is related to soil and water conservation practices. While its importance has been recognized, infiltration data applicable to different land and cover conditions remain limited. In an effort to furnish these data a number of investigators have sought to develop a method whereby an index of the infiltration associated with field areas under conditions of natural rainfall can be obtained. Some knowledge of the conditions influencing soil permeability will be recognized to be of equal importance. The limitations of results obtained by various methods for estimating the infiltration which will occur in field areas can be judged only if the process involved is understood. It seems probable also that a better knowledge of the factors which influence soil permeability would contribute much to the development of conservation practices which would incorporate the most effective functioning of this important process.

The results of some exploratory infiltration tests made on Houston black clay, following the general procedure outlined by Musgrave (4),[3] indicated that individual measurements obtained by this method varied widely. A series of infiltration tests were made to check preliminary tests and to determine if a usable index of infiltration could be obtained. Supplementary studies were made of conditions in the soil cylinders which might be expected to modify soil permeability.

METHODS AND PROCEDURE

Two areas of Houston black clay were selected. These areas were similar in all respects except their present cover and cultural history. The soil in both areas developed from parent material representing the same geologic section. One area retained its virgin vegetative cover of native prairie grasses and the other was a cultivated area cropped to cotton. The cultivated area had been under cultivation for over 50 years, being utilized over this period chiefly for the production of cotton and corn.

Infiltration rates[4] on soil cylinders were determined in a mánner similar to the procedure outlined by Musgrave (4). Briefly, it consisted of jacking steel tubes into the ground and adding water to the surface of the soil inclosed by the tube at a rate equal to the rate of penetration. The addition of water was made from a burette, the additions being controlled automatically by the water level in the tube. The quantity of water penetrating the soil was determined from burette readings made periodically. To minimize the influence of soil variation

[1]Contribution from the U. S. Dept. of Agriculture, Hydrologic Division, Soil Conservation Service, Blacklands Experimental Watershed Project, Waco, Texas. Received for publication July 3, 1940.

[2]Associate Soil Technologist and Junior Soil Technologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 866.

[4]Glossary of terms used in Soil Conservation Service. SCS-MP-15, October. 1936.

the tubes were installed as close together as seemed practical. The tubes used were 6 inches in diameter and of two length groups, 19 inches and 38 inches, respectively. In the meadow area a group of five 19 inch and five 38 inch tubes were installed in two rows of five tubes each. The rows were 2 feet apart and the tubes 2 feet apart in the rows. The tubes representing the two length groups were installed at random. A group of five 19 inch tubes were installed in the cultivated area in one row with the same spacing. Prior to the application of water a perforated disc was placed on the surface of the soil, the sparse second growth of dry grass which occupied the meadow area being first cut close to the ground in the tubes.

Just prior to beginning the infiltration tests the soil was sampled at six points surrounding the group of tubes in the meadow area and five points surrounding the tubes in the cultivated area. At each sampling point samples were obtained for the following depths: 0–6 inches, 6–12 inches, 12–24 inches, 24–36 inches, 36–48 inches, and 48–60 inches, and the moisture content determined. The moisture content of the soil in the tubes at the begining of the test was computed from the average moisture content of these samples.

The elevation of the soil surface inside and outside each tube was determined from a fixed point on the tube before the addition of water and after the completion of the measurement for the purpose of determining the volume occupied by the incased cylinder of soil at the two moisture contents.

The infiltration tests were made in the two areas in close succession. Water was supplied to all the cylinders at one site simultaneously, the initial additions to the individual cylinders being spaced in a manner which would distribute the time for making the required observations. Burette readings were taken every 5 minutes for the first 20 minutes, then every 10 minutes until the end of the first hour. During the second hour readings were taken every 15 minutes, and during the remainder of the test readings were taken every half hour. The application of water was continued for 48 hours.

Immediately upon completion of the measurements two tubes of each length, one in which the infiltration had been very high and one in which it had been very low, were excavated. The tubes and incased soil cylinders were weighed, following which the soil was carefully removed from the tubes, dried at 110° C, reweighed, and the weight of dry soil and moisture content computed. A careful visual check was made during the time the soil was being removed from the tube for water passageways and structural differences which might be used to interpret the different infiltration values obtained.

The remaining six tubes in the meadow area and the remaining three in the cultivated area were left in place for 41 days, following which infiltration was measured again to determine what, if any, effect long-continued high moisture content had on soil permeability. These cylinders of soil were maintained at approximately field capacity during this interval by the addition of water periodically and protection against evaporation losses by the use of moist felt discs on the soil surface supplemented by loose-fitting covers over the tubes. Following the second measurement the tubes in the meadow were left in place with the soil surface protected from drying by the moist felt disc and the tube covers for 13 days, to provide an opportunity for complete drainage of gravitational water. At the end of this period the tubes were excavated and the weight of dry soil and moisture content determined as in the case of the cylinders removed after the first measurement. The second infiltration measurement on the cylinders of cultivated land covered 34 days, immediately following which the

tubes were excavated and the dry soil and moisture content determined as previously outlined. Time was not allowed for the soil to drain since the movement of water through the incased soil cylinder was so slow the possibility of establishing an equilibrium in a reasonable length of time seemed doubtful.

To afford a means of studying the percolation[5] process and its relation to pore space and moisture distribution, two long and two short tubes were installed in the meadow area and two short tubes in the cultivated area. Following the installation the tubes were excavated. These incased soil cylinders were transported to the laboratory and infiltration determined there in a manner similar to that by which it was determined in the field. To obtain an accurate measure of the moisture content each tube and incased soil cylinder was weighed before and after the measurement. As a means of studying the relation between the entrance of water into the soil and its subsequent distribution in the soil, the time required for percolation to begin was noted, as also the quantity of water which had entered the soil at the time percolation began.

The percolate was measured periodically during the time water was added to the soil and for the period between the time the water just disappeared from the surface of the soil until drainage stopped in an effort to learn something of the time required to saturate the soil and the quantity of gravitational water present at saturation. Following the completion of the measurement, the soil was removed from the tubes, dried, and weighed.

RESULTS AND DISCUSSION

The highly variable infiltration rates indicated by preliminary tests on in-place cylinders of field soil were confirmed. A number of investigators have called attention to the wide variation in the permeability exhibited by soil cylinders representing a given soil and field condition and emphasized that field infiltration characteristics must be based on a value obtained through the use of a large number of cylinders.

Slater and Byers (6) conclude that water passageways provided by root channels and structural cleavage govern field percolation rates more than the character or volume of the pore space of the soil mass. The infiltration rates obtained on incased cylinders of Houston black clay under both field and laboratory conditions support these conclusions. Examination of the soil cylinders after the 48-hour tests showed that even where large quantities of water had passed through the cylinders, the soil had not always been uniformly wetted but contained vertical zones exhibiting different degrees of wetness. The soil material in the wetter zones appeared to have a slightly looser structure. The infiltration in 48 hours could be accounted for in seven of the cylinders by the increase in moisture content of the cylinder. An examination of these cylinders gave no evidence that water had percolated through them. The soil in the upper portion of these cylinders was wet, but the soil underneath had received little or no water.

While, as previously stated, the infiltration rate as determined for individual soil cylinders varies within wide limits, there appears to be a significant difference in the rate and the change in rate with

[5]See footnote 4.

time directly attributable to soil and experimental conditions. The highest rates were obtained on the short cylinders from meadow land and the lowest on the cylinders from cultivated land. The initial infiltration rate obtained in every test was high. There was less difference between rates obtained on the three groups of cylinders representing different land and experimental conditions, initially, than was obtained as the application of water continued. As the time of application increased, rates obtained on each group became more widely different. It will be observed (Table 1 and Fig. 1) that the infiltration rates approached minimum values after 2 hours in the cultivated area but that 12 to 24 hours or longer were required for the rates on the two groups of cylinders in the meadow area to approach

TABLE 1.—*Infiltration rates determined on cylinders of undisturbed soil.*

Soil cylinder	Initial length, inches	Infiltration rate, surface inches per hour							Percolate, surface inches, 0 48 hrs.*
		0–5 min.	5–30 min.	½–2 hrs.	2–12 hrs.	12–24 hrs.	24–46 hrs.	46–48 hrs.	
				Cultivated Land					
1†	17.1	11.16	0.60	0.17	0.05	0.02	<0.01	<0.01	0.0
2	16.6	21.00	1.94	0.26	0.05	0.01	0.02	0.01	0.0
3	16.8	24.84	1.10	0.31	0.06	0.02	0.02	0.02	0.0
4	16.9	13.44	1.99	0.50	0.12	0.02	0.01	0.01	0.2
5	16.4	17.52	2.18	0.37	0.11	0.03	0 01	<0.01	0.0
6	16.4	62.04	2.76	0.61	0.15	0.06	0.06	0.06	5.8
Average	16.7	25.00	1.76	0.37	0.09	0.03	0.02	0.02	
				Meadow Land					
11	15.5	34.68	5.06	1.03	0.25	0.15	0.12	0.12	10.6
12	16.1	46.08	16.27	4.45	1.97	0.58	0.28	0.18	46.1
13†	17.1	29.52	15.46	6.59	1.63	0.59	0.40	0.39	46.4
14†	17.1	30.00	23.04	10.03	4.31	2.97	1.41	0.98	133.8
15	16.1	37.32	18.74	12.66	6.48	3.30	1.62	0.84	168.9
16	16.4	33.60	35.30	24.59	12.27	5.14	4.26	3.24	335.0
17	15.6	42.36	48.77	37.01	19.72	8.73	6.23	4.82	524.3
Average	16.3	36.22	23.23	13.77	6.66	3.07	2.05	1.51	
				Meadow Land					
21†	34.0	30.36	3.07	0.03	<0.01	<0.01	<0.01	< 0.01	0.0
22	33.5	23.64	5.26	0.27	0.04	0.01	0.01	0.01	0.0
23	34.9	30.00	5.04	0.02	<0.01	<0.01	<0.01	<0.01	0.0
24†	35.5	49.56	15.14	4.05	0.34	0.11	0.07	0.05	14.6
25	34.9	36.60	24.31	5.58	0.37	0.08	0.05	0.04	19.6
26	34.5	37.32	15.38	12.05	5.48	1.56	0.69	0.48	109.9
27	34.8	65.88	25.46	11.21	5.56	2.59	0.64	0.46	127.2
Average	34.6	39.05	13.38	4.74	1.69	0.62	0.21	0.15	

*Computed for cylinders run in field. Measured on cylinders run in laboratory.
†Cylinders excavated prior to making infiltration determinations.

a minimum value. The time required on the average for infiltration to approach a constant rate was greater for the short cylinders than for the longer cylinders.

These results are better understood when the physical and chemical characteristics and initial field condition of the soil are noted. Mechanical analyses (5) and moisture equivalent (2) determinations of samples obtained adjacent to the location at which the infiltration tests were made indicate the uniformity of texture and heavy nature of the soil (Table 2). An intensive study of the physical and chemical

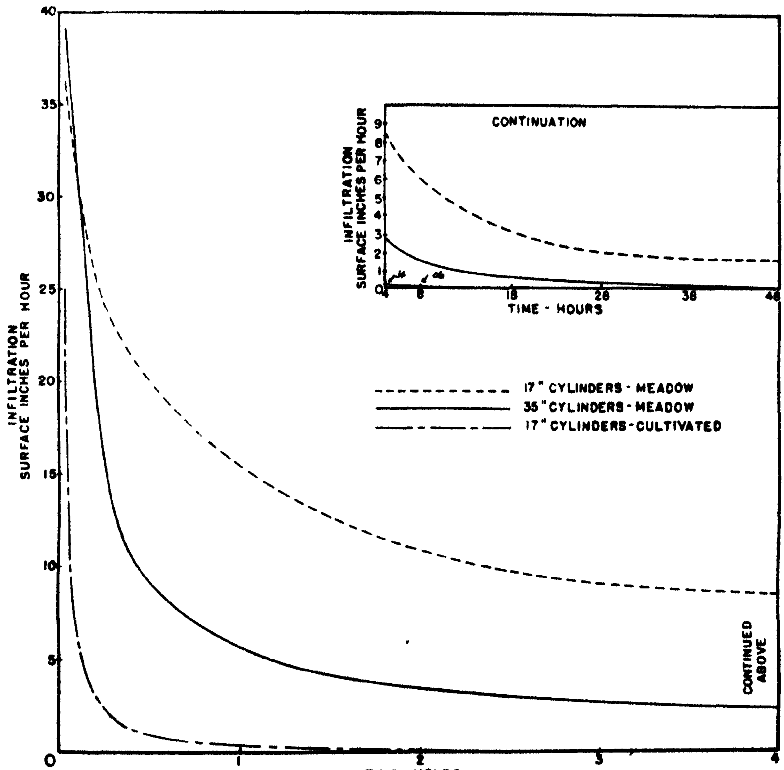

FIG. 1.—Infiltration rates, average of cylinder groups.

properties of Houston black clay is reported by Middleton, *et al* (3). Field observations at the time the tests were made indicated dry weather cracking was general and that cracking was more intensified in the meadow than the cultivated land. The surface of the meadow land had a granular structure with many fine interconnecting cracks. Below the surface 6 inches cracks were numerous but became less frequent with increasing depth. The cracks attained their maximum size at a depth of about 2 feet. In the cultivated area the cracks were obscured by the loose surface soil, but below this they were well defined but less numerous and not as deep as in the meadow area,

The difference in the extent of cracking in the two areas is indicated by the different moisture content of the soil in the two areas (Table 3).

TABLE 2.—*Mechanical analyses and moisture equivalents of samples taken near infiltration tubes.*

Depth, inches	Sand, 2.0–0.05 mm, %	Silt, 0.05–0.002 mm, %	Clay, <0.002 mm, %	Organic matter by H_2O_2, %	Moisture equivalent, %
		Meadow Land			
0–2	9.8	35.8	49.4	5.0	41.2
5–7	7.8	35.8	52.6	3.8	40.7
11–13	8.2	37.2	53.2	1.4	37.2
23–25	7.9	38.2	53.1	0.8	34.1
35–37	7.4	38.2	53.2	1.2	34.3
47–49	5.8	42.0	51.5	0.7	34.6
59–61	5.2	41.8	52.4	0.6	36.3
		Cultivated Land			
0–2	13.6	34.0	51.0	1.4	33.5
5–7	9.0	35.3	54.5	1.2	38.1
11–13	9.0	35.2	54.9	0.9	39.0
23–25	7.8	36.0	55.2	1.0	42.1
35–37	7.7	37.8	53.9	0.6	49.0
47–49	8.0	37.2	54.1	0.7	51.2
59–61	7.7	37.2	54.4	0.7	50.0

TABLE 3.—*Soil moisture.*

Depth interval, inches	Percentage moisture						Average, %
			Meadow Area				
0–6	14.9	14.1	16.5	14.5	14.3	16.7	15.2
6–12	18.1	18.9	18.2	17.0	17.5	19.8	18.2
12–24	16.6	18.1	16.9	16.3	17.2	18.1	17.2
24–36	16.8	17.7	17.2	16.1	17.3	17.9	17.2
36–48	18.9	19.1	17.8	17.8	18.3	18.6	18.4
48–60	19.7	20.5	19.5	21.1	20.3	19.9	20.2
			Cultivated Area				
0–6	13.7	12.6	13.2	11.4	13.4	—	12.9
6–12	20.8	20.3	19.9	15.1	22.2	—	19.7
12–24	22.5	23.0	22.2	19.6	23.5	—	22.2
24–36	23.7	24.0	23.9	22.4	23.4	—	23.5
36–48	24.7	25.3	23.7	23.6	24.0	—	24.3
48–60	26.1	26.8	25.7	24.4	17.6	—	24.1

The observed vertical zones of different wetness indicate the presence of water passageways. The assumption that continuing high rates contributing to deep percolation are dependent upon the presence of water passageways rather than total porosity is supported by the fact that in the cylinders through which little or no water percolated the infiltration rates dropped very abruptly to near the

minimum rate. Also, that if percolation through the cylinder took place at all, it occurred in the first few minutes after the initial application of water, as will be indicated by data to be discussed later in the paper (Table 7). A volume of water, equal in some cases to 30 times the volume of the cylinder, percolated through the cylinder in 48 hours. This is evidence that water is percolating to considerable depths or that a mass of soil having a much larger cross-sectional area than the cross-sectional area of the inclosed cylinder is acting as a reservoir for the percolating water. Since evidence indicates percolation through the soil and underlying strata takes place largely through water passageways which are often interconnected, the cumulative infiltration measured by this method is believed not a measure of the cumulative capacity of the soil corresponding to an area of land surface equal to the cross-sectional area of the soil cylinder, but represents the approximate storage capacity of the cylinder and an undefined adjacent soil mass below the base of the tube into which the water moves laterally, as well as downward, as soon as it percolates below the obstruction offered by the casement. The enlarged wet area observed at the base of the excavated tubes is positive proof that the percolating water spread laterally to some extent.

The character of the pore space contributing to soil permeability advanced in explanation of the infiltration rates obtained is supported by a variety of evidence. The high infiltration rates in the first 5 minutes is evidence the first few inches of the surface is highly permeable when the soil is dry.

It is assumed that high initial infiltration rates can be attributed to water entering the loose, granular, surface soil, filling the voids to a depth of a few inches almost immediately. It is believed continuing high rates are dependent upon cracks or other water passageways in the cylinder which connect with others below and outside the tube. The high rates maintained over a relatively long time, it appears, can only be explained by assuming that some of these water passageways are rather stable under the conditions of the measurement and connected to an underground reservoir of large capacity. The so-called reservoir capacity is believed to consist of interconnected cracks or water passageways which underlies a rather extensive surface area. The low rates attained in the cylinders of cultivated land and in three cylinders of meadow land before the moisture deficit of the soil has been satisfied probably can be attributed to a lack of interconnected water passageways through the cylinder, or to an abnormally large reduction in the size of the water passageways due to the swelling of the soil which takes place upon wetting.

The smaller cumulative infiltration measured on the cylinders of meadow land incased by the long tubes compared to those incased by the short tubes is attributed to the effect of the tube wall in cutting off water passageways. The probability that a considerable number of water passageways will be intercepted by the tube as it is forced vertically into the soil is obvious when it is recognized that these passageways do not always lead vertically into the soil but may proceed at an angle or be tortuous in character.

Assuming that the tube wall does intercept water passageways and that all water passageways are not interconnected within the soil mass bounded by the tube, the tube walls may block the further downward movement of water through the passageways cut off by the tube. Other water passageways existing in the subsurface may be directly connected to the surface only at a point outside of the tube and consequently rendered ineffective as water passageways for transmitting water through the soil incased by the tube. The tube wall will thus tend to cause infiltration determined on an incased cylinder of soil to be lower than if water was applied to an equal surface area in the absence of a tube. On the other hand, if some water passageways are continuous through the soil cylinder incased by the tube, the water transmitted through the cylinder would have an opportunity to spread into surrounding passageways. This would tend to give an abnormally high measure of infiltration.

It is believed that the extent to which depth of incasement will modify infiltration data obtained by this method will depend upon the character of the pore space responsible for percolation and the sequence of permeability factors in the soil profile. Standardization in length of casement does not overcome this objection since soil characteristics governing permeability would be expected to modify the influence which the casement would exert, thus the rates obtained for different soils are not strictly comparable and the method cannot be depended upon to furnish a reliable index of infiltration characteristics.

The question may be raised as to the extent which the casement will modify percolation as the cross-sectional dimensions of the soil cylinder is increased. While the effect of this factor was not included in our study it is expected it would be proportional to the ratio of the perimeter of the casement and the surface area to which water is applied. Consequently, the larger the cross-sectional area of the soil cylinder, the less should be the modifying influence of the casement.

Evidence that earthworms were active in some of the cylinders of meadow land was observed about a week before infiltration measurements were made the second time. The soil cylinders were maintained in a moist condition for 41 days between the first and second measurement. The presence of earthworms was confirmed when the cylinders were excavated and the soil removed from the tubes. Normally, under moisture conditions which existed in the area, earthworms are not found above the 4-foot depth. It is believed the earthworms in the tubes moved in from the adjacent wetted area below the base of the tubes, consequently the numbers found cannot be considered an index of the density of the earthworm population in the area.

Infiltration rates were materially higher in the cylinders containing earthworms than the rates at the completion of the first determination. These higher rates persisted throughout the measurement, a period of 10 hours (Table 4). It is of interest to note that the degree to which the infiltration rate increased corresponded to the number of large earthworms in the soil cylinder. No earthworms were found in the cylinders of cultivated land and it has been observed that while

earthworms are quite numerous in the Houston black clay supporting a grass cover, they are found infrequently in cultivated areas.

TABLE 4.—*Effect of earthworm activity on infiltration rates.*

Soil cylinder	Infiltration, surface inches per hour								Earthworms in cylinders*	
	Initial run	Wet run							Large	Small
Meadow Land										
	46–48 hrs.†	5 min.	5 min.–1 hr.	1–2 hrs.	2–4 hrs.	4–6 hrs.	6–8 hrs.	8–10 hrs.		
16	3.24	12.24	2.96	6.17	7.30	8.98	7.22	7.04	2	23
15	0.84	12.84	1.92	2.09	2.34	2.52	2.75	2.24	1	20
27	0.46	14.88	2.12	1.74	1.45	1.30	1.30	1.31	1	21
11	0.12	12.48	0.16	0.02	0.10	0.12	0.14	0.14	0	38
25	0.04	7.20	0.35	0.12	0.08	0.08	0.07	0.08	1	9
22	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Cultivated Land										
		0–3 days	3–6 days	6–14 days	14–23 days	23–30 days	30–32 days	32–34 days		
5	<0.01	0.002	0.002	0.003	0.002	0.001	0.001	0.001	0	0
2	0.01	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0	0
3	0.02	0.003	0.004	0.004	0.003	0.002	0.002	0.002	0	0

*Large earthworms 4 inches or longer, small earthworms 2 inches or shorter.
†Data taken from Table 1. The values appearing in this column were obtained 41 days prior to those in the following columns. High moisture content maintained during 41-day interval.

Maintaining cylinders of cultivated land in a saturated condition over a long period of time appeared to reduce infiltration rates. The rates at the end of the 48-hour initial test, however, had already become so low that the further decrease shown may not be significant.

The relative volumes of soil, water, and air in the cylinders were determined in an attempt to provide an explanation of the erratic infiltration behavior of individual cylinders representing a similar land and cover condition. The volumes occupied by the cylinders in their initial relatively dry and their subsequent wet condition were computed from the measured dimensions of the incased cylinders in the two conditions. The apparent density and the percentage by volume of soil, water, and air in the individual cylinders before and after the infiltration determinations are given in Table 5 for the three groups of cylinders, in the order of their increasing infiltration capacities.

A highly significant correlation was found between apparent density and infiltration for the short cylinders. The correlation for the long cylinders was less significant (Table 6). It will be noted that this is the case over a number of selected intervals. This does not infer, however, that the permeability of the cylinders is a function

TABLE 5.—*Comparison of porosity factors at two moisture levels.*

Soil cylinder	Apparent density			Soil, % by volume			Air, % by volume			Water, % by volume			Water content, surface inches		
	Dry	Wet	Diff.	Dry	Wet	Diff.	Dry	Wet	Diff.	Dry	Wet	Diff.	Dry	Wet	Diff.
1*	1.427	1.295	0.132	52.9	48.0	4.9	21.0	15.0	6.0	26.1	37.0	10.9	4.94	6.98	2.04
2	1.326	1.250	0.076	49.1	46.3	2.8	27.2	6.4	20.8	23.7	47.3	23.6	3.95	8.33	4.38
3	1.277	1.214	0.063	47.3	45.0	2.3	29.8	9.3	20.5	22.9	45.7	22.8	3.83	8.06	4.23
4†	1.324	1.277	0.047	49.1	47.3	1.8	27.2	8.0	19.2	23.7	44.7	21.0	4.00	7.81	3.81
5	1.305	1.267	0.038	48.3	46.9	1.4	28.3	4.9	23.4	23.4	48.2	24.8	3.83	8.13	4.30
6†	1.209	1.173	0.036	44.8	43.4	1.4	33.6	7.8	25.8	21.6	48.8	27.2	3.54	8.24	4.70
Av.	1.311	1.247	0.065	48.6	46.2	2.4	27.8	8.6	19.3	23.6	45.3	21.7	4.02	7.93	3.91
11*	1.280	1.230	0.050	48.3	46.4	1.9	29.9	15.1	14.8	21.8	38.5	16.7	3.38	6.21	2.83
12†	1.278	1.239	0.039	48.2	46.8	1.4	30.0	7.2	22.8	21.8	46.0	24.2	3.51	7.64	4.13
13*‡	1.274	1.247	0.027	48.1	47.1	1.0	30.9	10.9	19.9	21.0	42.0	21.0	2.33	7.34	5.01
14*‡	1.226	1.175	0.051	46.3	44.3	2.0	31.5	10.0	22.8	22.2	45.7	23.5	3.25	8.17	4.92
15‡	1.215	1.179	0.036	45.8	44.5	1.3	33.5	21.1	12.4	20.7	34.4	13.7	3.34	5.72	2.38
16‡	1.246	1.209	0.037	47.1	45.6	1.5	31.7	13.1	18.6	21.2	41.3	20.1	3.48	6.97	3.49
17†	1.134	1.082	0.052	42.8	40.8	2.0	37.9	19.4	18.5	19.3	39.6	20.3	3.02	6.52	3.50
Av.	1.226	1.194	0.032	46.7	45.1	1.6	32.2	13.8	18.5	21.1	41.1	19.9	3.19	6.94	3.75
21*	1.438	1.407	0.031	54.3	53.1	1.2	19.8	9.6	10.2	25.9	37.3	11.4	7.91	12.97	5.06
22	1.351	1.297	0.054	51.0	49.0	2.0	26.0	8.3	19.4	23.0	42.7	21.4	7.65	14.77	7.12
23†	1.470	1.449	0.021	55.5	54.7	0.8	19.5	5.4	14.1	25.0	39.7	14.7	8.73	14.03	5.30
24*‡	1.330	1.303	0.027	50.2	49.2	1.0	27.0	9.4	17.6	22.8	41.4	18.6	6.90	15.01	8.11
25‡	1.313	1.299	0.014	49.5	49.0	0.5	28.1	8.3	19.8	22.4	42.7	20.3	7.80	15.05	7.25
26†	1.347	1.328	0.019	50.8	50.1	0.7	26.2	7.4	18.8	23.0	42.5	19.5	7.92	14.88	6.96
27‡	1.315	1.296	0.019	49.6	48.9	0.7	28.0	9.1	18.9	22.4	42.0	19.6	7.78	14.81	7.03
Av.	1.366	1.340	0.026	51.6	50.6	1.0	24.9	8.0	17.0	23.5	41.3	17.9	7.81	14.50	6.69

*Cylinders excavated prior to making infiltration determination.
†Cylinders excavated within a few hours after the completion of the infiltration determination
‡Cylinders used for the computation of field capacity.

of the total porosity without reference to the distribution of this porosity. The fact that the high cumulative infiltration for several individual cylinders was not accompanied by correspondingly low apparent densities is evidence the distribution of the pore space is an important factor. Additional evidence is presented later (Table 8). It is conceivable that the incased soil mass might normally occupy a greater volume when wet than the volume defined by the tube walls. Swelling which would occur upon wetting would be expected in such an instance to compact the soil. If compaction results, Baver (1) has shown the non-capillary pore space will be reduced proportionately more than the total pore space.

TABLE 6.—*Correlation coefficients between volume weights and infiltration.*

Comparison	Correlation coefficients	
	19 inch tubes	38 inch tubes
Volume weight of soil before run with infiltration for:		
First 5 minutes	−0.733	−0.545
First 2 hours	−0.730	−0.730
48 hours	−0.780	−0.506
Volume weight of soil after run with infiltration for:		
Last 2 hours	−0.738	−0.344
48 hours	−0.858	−0.407

Minimum value for significance (19 inch tubes) P = .02 r = .634
P = .01 r = .684
Minimum value for significance (38 inch tubes) P = .10 r = .669
P = .05 r = .754

The initial water content of the cylinders was assumed to be the average moisture content of the samples obtained from the immediate vicinity of the group of cylinders. Consequently, the moisture content of individual cylinders, except the excavated cylinders, is not strictly quantitative. The excavated cylinders indicated the computed moisture content of the soil cylinder differed from the true value by not over 1.0% moisture by weight.

The elevation of the soil surface in the tubes increased, without exception, upon wetting. The difference in the apparent density of the dry and wet cylinders reflects the change in volume resulting from swelling.

The field capacity, or water held against free drainage, was computed for the individual cylinders of meadow land through which there was percolation. The degree to which drainage was unimpeded probably is reflected by the volume of percolate (Table 1). Limiting computations of field capacity to cylinders which permitted some drainage seems necessary as it constituted the only evidence that the gravitational water had functional freedom and even where considerable percolation occurred this probably did not constitute evidence that entrapped gravitational water is not present in some

portions of the cylinder or that all of the cylinder was wetted to capacity. The field capacity so determined was somewhat variable, but the average values were in fair agreement with field moisture determinations made in the locality during prolonged wet periods.[6]

The difference in the water content of the soil cylinders excavated immediately and those allowed to drain in place for 13 days was not significant, as will be seen by comparing the water content of cylinders 12 and 17 with cylinders 11, 15, and 16, and cylinder 26 with cylinders 25 and 27, in the wet condition (Table 5). A comparison of the water content of cylinders 11, 15, and 16, with cylinders 13 and 14, and cylinders 25 and 27 with cylinder 24, contrary to expectations, shows no consistent difference in the quantity of water held against gravity when the cylinder was continuous with underlying material and when it was broken as is the case with the excavated cylinders.

Periodic determinations of infiltration and percolation with excavated soil cylinders were made for two long and two short cylinders of meadow land and one cylinder of cultivated land (Table 7). After 48 hours no percolation had taken place through one long soil cylinder of meadow land or through the cylinder of cultivated land, although water was applied continuously. In the soil cylinders through which percolation did take place it occurred within 3 minutes or less from the time water was applied, indicating that they contained some water passageways which offered little resistance to the movement of water and that percolation is dependent largely on these water passageways. The quantity of water which had entered the soil at the time percolation began was considerably less than required to bring the soil to saturation. It is of interest to note that at the end of the test, but before gravitational water had an opportunity to drain from the cylinders, approximately 10% or more of the pore space was still occupied by air. It is not believed that this can be attributed entirely to interference which the cylinder walls may have exerted but to a condition normally present in the soil under field conditions.

TABLE 7.—*Soil moisture content in relation to percolation and saturation of soil cylinder.*

Soil cylinder	Time required for percolation to begin, min.	Time at which sufficient water had been added to have completely filled the pore space of the cylinder, min.	Percentage initial saturation	Percentage saturation attained at time shown in column 3	Percentage saturation finally attained
1	No percolate	—	55.4	—	71.1
21	No percolate	—	56.7	—	79.5
24	3 min.	24 min.	45.8	80.1	87.9
13	3 min.	13 min.	40.5	75.1	87.5
14	2½ min.	12 min.	41.3	70.2	90.5

[6]Unpublished soil moisture data.

In the cylinders through which percolation took place the pore space occupied by air was increased as a result of drainage. The increase in the pore space occupied by air is assumed to be the pore space effective in transmitting water (Table 8).[7]

TABLE 8.—*Pore space effective in transmitting water at the completion of a 48-hour infiltration measurement.*

Soil cylinder	Percentage of total pore space			Infiltration, surface inches per hour, 46–48 hours
	Pore space occupied by air at maximum water-holding capacity attained	Pore space occupied by air after drainage of gravitational water	Pore space transmitting water*	
1	28.9	28.9	0.0	<0.01
21	20.5	20.5	0.0	<0.01
24	12.1	18.5	6.4	0.05
13	12.5	20.7	8.2	0.39
14	9.5	17.9	8.4	0.98

*Assuming that the increase, due to drainage, in the pore space occupied by air is the pore space effective in transmitting water

CONCLUSIONS

The great variation in infiltration as measured on soil cylinders representing a given land condition can likely be attributed to three factors, *viz.*, the inherent variation in the permeability of the soil, the extent to which this permeability is rendered ineffective by the tube wall acting as a barrier to water, and the extent of lateral spreading below the tube wall.

The high infiltration rates which persisted in a number of cylinders for a considerable time indicate a continued high permeability in these cylinders, however, the amount of water passing through the cylinders cannot be considered to reflect the reservoir capacity of the cylinders and the underlying material of equal cross-sectional area.

Earthworm activity was found to increase infiltration appreciably when conditions are such that earthworms extend their burrows to the surface.

The permeability of the soil cylinders is not a function of the total porosity of the cylinder without reference to the distribution of that porosity but is dependent almost entirely on water passageways or zones of above average porosity.

Prolonged wetting was not effective in displacing all air from the soil pores, but in every case an appreciable percentage of the pore space continued to be occupied by air.

The pore space in Houston black clay effective in transmitting gravitational water is limited to a small percentage of the total pore space and is not measured by the space occupied by air at field capacity.

[7]It is to be noted that the infiltration rates obtained during the latter part of the run correspond in order though not in magnitude with this increase in pore space.

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READING FOR SOIL SCIENTISTS, TOGETHER WITH A LIBRARY[1]

CHARLES E. KELLOGG[2]

I. READING

READING is largely a matter of habit. Such habits, like others, are usually acquired early in life, although frequently in later years. They may be good or bad and, like all habits, may be changed for better or worse as time goes on. The habit of much reading is not necessarily a virtue; it may be simply an escape from some more unpleasant alternative, such as helping with evening chores or the effort of thinking on one's own account.

A lot is said about "purposeful" reading as contrasted to reading for "pleasure". These categories really do not mean much, however, because people do not agree on the meaning of either "purposeful" or "pleasure". Some people get pleasure from following the simple intricacies of a detective story while others, who detest detective stories, may enjoy a book like Spengler's *Decline of the West*—are hardly able to lay it down. One of my friends finds great joy in sitting up late before the fire and reading Pliny and Horace in the original. Most of us wouldn't.

Most people will not read much unless they derive a certain satisfaction from it. Some get satisfaction from the very music of word combinations. Others enjoy reading about places or experiences that recall to themselves pleasant places they have seen or pleasant experiences they have had. The important escape or "ivory tower" motive has been mentioned. Some people get satisfaction from learning, and reading offers one very important way of realizing this satisfaction. Most of those who like to read probably get more or less satisfaction in each of these ways.

For people of small or moderate means, reading offers the only practical method of becoming acquainted with the world, the nature of society, and the development of our culture. But then, some one may ask, why should anyone want to know these things? This is a question for the metaphysician; I shouldn't even attempt an answer. If we assume that one has this desire, whatever the reason, he has the first requirement for a general reader—the desire to know something about something. At the start, the objective may be very narrow, but it is liable to grow, first in one field and then from one to another. It seems as if the learning process, when stimulated from within, develops rapidly into a hopeless race. The more one reads and learns, the more things one finds that he wants to learn more about, because progress in one field depends upon others, and these, in turn, upon still others. As the process continues, new relationships appear that must be explored. One may begin in soil science, but if he follows it through he will dig into Aristotle, Shakespeare, Voltaire, and hun-

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dreds more before he is finished. Really, he never gets finished. A general reader is always behind with his reading.

It is rather a knowledge of relationships that the general reader seeks, not facts *per se*. He reads to enlarge his own experience. The encyclopedic mind, with each fact carefully insulated from every other one, does not satisfy the purpose we have assumed for our general reader.

As the reading goes on, understanding usually grows. In all writing the author assumes certain knowledge on the part of the reader. In especially serious books this demand on the reader may be great and an understanding of the author's work depend upon a broad knowledge of the classics of science and literature. A simple or even indirect reference to a historical or fictional character, place, or event is often used to convey some entire thought. Now, of course, one doesn't need to read such books. There are a good many others available that require but little background, very little indeed. But these are not likely to serve the purpose of our general reader, at least not entirely. This thought leads me to mention another purpose, or rather compensation, that reading has for the general reader. Widely read people seldom get lonesome; even when they have no books by them they have a rich storehouse of memories. A widely read old man on his deathbed was asked if he would say a last word to his waiting friends. He simply turned his head toward his books and said softly, "Goodbye, my friends".

The development of taste in reading is not for me to discuss except that I should like to emphasize the importance of internal stimulation. There is no great need to worry about not having read *Anthony Adverse*, *Rebecca*, or even *Gone with the Wind*. Not that these may not be good books, well worth reading perhaps, but because if one tries to "keep up" with all the current literary thrillers, so much reading will be required, since there is constantly a fresh crop each year, that the average ones of us will have time for nothing else. Except for professional critics who must, few widely read people, general readers, even attempt to keep well abreast of the current literature. Probably few if any soil scientists could possibly do so, and become general readers at the same time.

Then again some authors—even many of those widely acclaimed—may not interest us. They just are not somehow *simpático*. Perhaps we "can't get our teeth into the stuff". It is better to pass them by than to waste time that might be spent to better advantage on others. We must be careful, however, that we give the author a fair trial and not dismiss as adults what we, perhaps, could not understand as children. Here must be mentioned the very worst crime of many professional pedagogues. Frequently they take a great masterpiece, written for mature adults to read as a whole, pick it into unintelligible, undigestible pieces, and then serve it up, bit by bit, to young people who shouldn't be expected to understand it under normal conditions, let alone after mutilation. Especially when the pieces are garnished with an abundance of obvious gushiness, the youngster stands in a fair way of developing a thorough hatred of the classics—a feeling that may remain for the rest of his life. Names like Thackeray,

Shakespeare, and Emerson strike terror to his heart. And what a pity! For regardless of the purpose of reading—whether for education, as an escape, for amusement, or just to waste time—the classics are the best for it. Not because they are classics, but for the reasons that made them classics.

If for some reason one has this desire that makes a general reader, and it gets a real hold over him in the more aggravated form, he will want to look into all the various departments of knowledge. Not only will he become a reader, but a rapid reader. He will find that even in the best books a great deal may not be worth much time, especially since there will be so much ground to cover, so many more books ahead of him. Most widely read people are very rapid readers. The reading process is too painful to the slow reader; he would rather do something else. Unfortunately, many young people do not develop reading habits aside from their school books. Naturally, one reads those books upon which he may be examined more slowly, and if this kind of reading sets his pace, determines his reading habits, he will never become a wide reader. A bit of experience as a teacher I would like to suggest to other teachers trying to interest students in general reading, *viz.*, recommend books of special interest to the student (not the teacher) but don't ask the student about them afterward.

What should be the reading habits of a soil scientist? Each one will, of course, need to answer this question for himself. These habits will need to be adjusted to his other habits. If they are not, the answer always is, "I should do more reading; I would like to, but I haven't the time". Of course, this is rarely, if ever, true. The truth is simply that there are other things he would rather do. Then there is eye strain, the real kind and the convenient kind. Although a few suggestions follow, I have no illusions regarding either their applicability or their adoption.

First, let us assume that the prospective soil scientist has, for some reason that we cannot go into here, a desire to know much about soil science, its relationship to other sciences, and how his own work may contribute to the welfare of the society of which he, as an individual, is a part. He realizes that there are three great classes of relationships and that somehow he must realize a partial understanding of all three: (1) The relationship of facts to facts, the field of science; (2) the relationship of the man to the facts, the field of art; and (3) the relationship of man to man, the field of justice and morals. He strives to make his knowledge symmetrical and to develop completeness as an individual in society, as a citizen of the world as well as a specialist in soils. He finally comes to the realization that knowledge is, after all, one great body, not departmentalized, but a huge jewel with many facets.

It would be my thought that this scientist attempts to keep himself reasonably well informed upon current research in his own field and closely related fields. He doubtless receives regularly the publications of the Soil Science Society of America, the International Society of Soil Science, and the American Society of Agronomy. He also notes the important periodicals dealing with soil science and some of the closely allied fields. Without doubt he reads regularly the publications

of the American Association for the Advancement of Science. From these he proceeds to important monographs and books that have a special interest to him.

In more general fields he examines a few good newspapers and current magazines that include essays of interest and from which he is able to keep in touch with the several phases of our social and intellectual life. From these points of departure, he goes where he must to accomplish his purpose. Time and time again he needs to build in background material from the classics and from elementary books of many sciences. He may even read some books on the following list, or on better lists.

Our soil scientist has become a general reader!

II. A LIBRARY FOR A SOIL SCIENTIST

The following list of books has been prepared with the thought of suggesting a few that might be of value to one who is beginning soil science as a major line of interest. For a satisfactory concept of the place of science in contemporory life it is essential to have some appreciation of the nature and development of society and the ideas of people. These ideas have been expressed in novels, dramas, stories, and poems as well as in essays. Many kinds of people, in different places and at different times, have contributed their bit to the expression of our culture.

No one person, or group of persons, can pretend to make a very satisfactory reading list for another person. For one thing, such a list should include only those books with which the compiler is familiar. No one has been able to read all the good books, and all of us read a large number of mediocre ones for each one that appeals to us as exceptional, or even good. The list of books that follows comprises a few that its compiler has thought to be of special value to him. Many have been omitted that others might include simply because, for some reason, they did not appeal to this compiler. Unfortunately, there are many, many other good books that the compiler has not read—or even heard of for that matter. A few items have been omitted because of the difficulty of obtaining accurate versions in English, and a few for other reasons.

The titles are arranged in groups in order to distinguish roughly the technical books from those of more general interest. Of particular importance to the beginner in science are those works dealing with the philosophy of science and with the fundamental nature of the method, included in section IV. No significance whatever is to be attached to the order in which the titles appear in the list. Dates and other data are given only where helpful to identify a particular edition.

The compiler of this list is fully aware that it is open to serious criticisms on several grounds, including those of personal prejudice and narrowness of scope. Much better lists might exclude some titles and include many additional ones.

I. SOIL SCIENCE

1. Soils, their origin, constitution, and classification. G. W. Robinson. Murby. 1936.
2. Mother earth. G. W. Robinson. Murby. 1937.
3. Soil conditions and plant growth. Sir E. J. Russell. Longmans. 1937.
4. The soil. Sir A. D. Hall. Dutton. 1931.
5. The physical properties of the soil. B. A. Keene. Longmans. 1931.
6. The scientific study of the soil. N. M. Comber. Longmans. 1936.
7. Soils. E. W. Hilgard. Macmillan. 1906.
8. Soil fertility and permanent agriculture. C. G. Hopkins. Ginn. 1910.
9. Die Typen der Bodenbildung. K. Glinka. Borntraeger. Berlin 1914. (Also in English translation under the title "The great soil groups of the world and their development". C. F. Marbut. Ann Arbor. 1927.)
10. The evolution and classification of soils. E. Ramann. Translated by C. L. Whittles. Heffer. 1928.
11. Soil and civilization. Milton Whitney. D. van Nostrand. 1925.
12. International Congresses of Soil Science. Proceedings. 1st. Washington, 1927, 4 v.; 2d. Moscow, 1930, 6 v.; 3d. London, 1935, 3v.
13. Soils of the United States. C. F. Marbut. In atlas of American agriculture. Washington. 1935.
14. Soils and men. 1938 Yearbook of Agriculture.
15. The soils of Tennessee. C. F. Vanderford. Tenn. Agr. Exp. Sta. Bul. 10. 1897.
16. Pedology. J. S. Joffee. Rutgers. 1936.
17. The soil, its nature, relations and fundamental principles of management. F. H. King. Macmillan. 1916.
18. Manures and Fertilizers. Wheeler. Macmillan. 1913.
19. The group of papers covering the development of pedology in Russia prepared for the First International Congress of Soil Science. Leningrad. 1925. (In English.)

II. RELATED SCIENCES

20. Climate. W. G. Kendrew. Oxford. 1930.
21. The climates of the continents. W. G. Kendrew. Oxford. 1938.
22. Rocks, rock-weathering, and soils. G. P. Merrill. Macmillian.
23. Colloids. H. R. Kruyt. Wiley.
24. Outlines of theoretical chemistry. Getman and Daniels.
25. Outlines of biochemistry. Gortner. Wiley. 1938.
26. Principles of soil microbiology. Waksman. Baltimore. 1932.
27. Plant physiology. E. C. Miller. McGraw-Hill. 1938.
28. Plant physiology. N. A. Maximov. McGraw-Hill. 1938.
29. Crop production. Hughs and Henson. Macmillan.
30. Fundamentals of fruit production. Gardner, Bradford and Hooker. McGraw-Hill.
31. Elements of the differential and integral calculus. Granville. Ginn.
32. The determination of hydrogen ions. W. M. Clark. Williams & Wilkins.
33. The data of geochemistry. F. W. Clarke. U. S. G. S. Bul. 770. 1924.
34. Analytical chemistry. Treadwell and Hall. Wiley. 1930.
35. Production organization. Black and Black. Holt. 1929.

36. Race, sex, and environment; a study of mineral deficiency in human evolution. J. R. de la H. Marett. Hutchinson. London. 1936.
37. The formation of vegetable mould, through the action of worms with observations on their habits. C. Darwin, New York. 1882.
38. Geomorphology—A. K. Lobeck.

III. EARLY AGRICULTURE

39. Terra, a philosophical discourse of earth. John Evelyn.
40. Sylva, or a discourse on forest trees. John Evelyn.
41. Husbandry (De re rustica) L. J. M. Columella (written about 60 A. D.) English translation 1745.
42. Travels in France. Arthur Young.
43. Letters from an American farmer. J. Hector St. John Crevecoeur.
44. Geology and agriculture of Mississippi. E. W. Hilgard. 1860.
45. An essay on calcareous manures. Edmund Ruffin. 1852.
46. Roman farm management: a translation of Cato and Varro. "A Virginia Farmer". MacMillan. 1913.
47. Vegetable staticks. Stephen Hales. London. 1731–33.
48. The horse hoeing industry. Jethro Tull. London. 1731.
49. The natural laws of husbandry. Justus von Liebig. 1863.
50. The elements of agriculture. M. Duhamel du Monceau.
51. The Georgics. Virgil.

IV. SCIENCE: HISTORY, MEANING, METHOD, AND PHILOSOPHY

52. The nature of things. Lucretius. (Translation by Munro or Leonard).
53. History of the inductive sciences. William Whewell.
54. The advancement of learning. Francis Bacon.
55. The order of nature. L. J. Henderson.
56. Foibles of insects and men. W. M. Wheeler.
57. The biological basis of human nature. H. S. Jennings.
58. The universe in the light of modern physics. Planck.
59. The grammar of science. Karl Pearson.
60. The discourse on the method. Descartes.
61. Physical forces of nature. Faraday.
62. The chemical history of the candle. Faraday.
63. The nature of the physical world. A. S. Eddington.
64. Conservation of force and other essays. Helmholtz.
65. Introduction to mathematical philosophy. Bertrand Russel. London. 1919.
66. A system of logic. J. S. Mill. (Eighth or subsequent edition.)
67. The analysis of matter. Bertrand Russell.
68. The biology of death. Raymond Pearl.
69. Civilization and climate. Ellsworth Huntington.
70. The scientific outlook. Bertrand Russell.

V. PHILOSOPHY, CONDUCT OF LIFE, HISTORY, ETC.

71. The decline of the West. Oswald Spengler. Knopf.
72. The development of the understanding. Spinoza.
73. Essays and journal. Emerson.
74. Thus spake Zarathustra. Nietzsche.

75. The dialogues. Plato.
76. Sexual life of savages. Bronislaw Malinowski.
77. The tale of a tub. Jonathan Swift.
78. The Savoyard vicar. Rousseau.
79. The Bible.
80. The Dabistan, or school of manners. Masham Fani.
81. The golden sayings of Epictetus.
82. Counsels and maxims. Schopenhauer.
83. Liberty. J. S. Mill.
84. The Koran.
85. The American language. H. L. Mencken. Knopf. 1936.
86. The prince. Machiavelli.
87. Micromegas. Voltaire.
88. The Anti-Christ. Nietzsche. (Trans. by H. L. Mencken.)
89. The history of civilization in England. Buckle.
90. In praise of folly. Erasmus.
91. The eulogies, etc. Ovid.
92. Letters. Pliny the Younger.
93. Goodbye to western culture. Norman Douglass.
94. History of art. Elie Faure.
95. Knowledge for what? R. S. Lynd.
96. Freedom and culture. John Dewey.
97. Aesthetic. Benedetto Croce.
98. Democracy in America. Alexis C. H. C. de Tocqueville.
99. Essays. Montaigne.
100. The engineers and the price system. Veblen.
101. The theory of the leisure class. Veblen.
102. The anatomy of melancholy. Robert Burton.
103. Six rooms make a world. Gove Hambidge.
104. History of the United States. Henry Adams.
105. The modern corporation and private property. Berle and Means.
106. Democracy in crisis. Laski.
107. Whose constitution? H. A. Wallace.
108. The golden bough. Fraser.
109. Alice in wonderland. Carroll.
110. The Great Plains: a study in institutions and environment. Walter Prescott Webb.

VI. NOVELS AND STORIES

111. Madam Bovary. Flaubert.
112. An American tragedy. Theodore Dreiser.
113. The red and the black. Stendhal. (Beyle.)
114. The betrothed. Manzoni.
115. Lorna Doone. Blackmore.
116. The cloister and the hearth. Reade.
117. Don Quixote. Cervantes.
118. Penguin island. France.
119. Heloise and Abelard. George Moore.
120. Jurgen. Cabel.
121. Kristin Lavransdatter. Sigrid Undset.
122. Oliver Twist. Dickens.

123. The life and opinions of Tristram Shandy, gentleman. Sterne.
124. The portrait of the artist as a young man. James Joyce.
125. The brothers Karamazov. Dostoevsky.
126. Shiny night. Beatrice Tunstall.
127. The picture of Dorian Gray. Oscar Wilde.
128. Fräulein Else. Schnitzler.
129. The remembrance of things past. Marcel Proust.
130. Vanity fair. Thackeray.
131. Madamoiselle du Maupin. Gautier.
132. Fathers and sons. Turgenev.
133. The devil's pool. George Sand.
134. Pilgrimage. Dorothy M. Richardson.
135. Look homeward, angel; Of time and the river; The web and the rock; and You can't go home again. Woolfe.
136. Breaking point. Artzibashef.
137. Alexander-platz Berlin. Doblin.
138. The Buddenbrooks. Mann.
139. Sons and lovers. D. H. Lawerence.
140. Arrowsmith. Sinclair Lewis.
141. The world's illusion. Wasserman.
142. The 42nd parallel. John Dos Passos.
143. Studs Lonigan. Farrell.
144. Tom Jones. Fielding.
145. Of human bondage. Maugham.
146. War and peace. Tolstoy.
147. Anna Karenina. Tolstoy.
148. The way of all flesh. Butler.
149. Jude the obscure. Hardy.
150. Green mansions. W. H. Hudson.
151. Maria Chapdelaine. Hémon.
152. The pleasant memoirs of the Marquis de Brandomin. Valle-Inclau.
153. Indian lilies. Sudermann.
154. The book of the thousand nights and one night. Burton translation.
155. Messer Marco Polo. Byrne.
156. Candide. Voltaire.
157. The Princess of Babylon. Voltaire.
158. Stories. De Maupassant.
159. Stories. D. H. Lawrence.
160. Stories. Poe.
161. The monk and the Hangman's daughter. Bierce.
162. Stories. Andreyev.
163. Stories. Katherine Mansfield.

VII. BIOGRAPHY

164. The life of Washington. Hughs.
165. The life of Samuel Johnson. Boswell.
166. The romance of Leonardo da Vinci. Merejkowski.
167. Pepys' diary.
168. John Evelyn's journal.
169. Figaro: the life of Beaumarchais.

170. Confessions. Rousseau.
171. The memoirs of Casanova.
172. The autobiography of Benvenuto Cellini.
173. Franklin. Faÿ.
174. O Rare Ben Jonson. Steel.
175. The education of Henry Adams. Henry Adams.
176. The life of Robert Burns. Catherine Carswell.
177. Leonardo da Vinci. Antonina Vallentin.

VIII. DRAMA AND POETRY

178. She walks in beauty, Maid of Athens, Childe Harold, Don Jaun, etc. Lord Bryon.
179. Poems. T. S. Elliot.
180. Adonias, The hymn of Pan, Ode to the west wind, etc. Shelley.
181. The rime of the ancient mariner, etc. Coleridge.
182. The land. V. Sackville-West.
183. The Congo. Vachel Lindsay.
184. Sonnets from the Portuguese, A musical instrument, etc. E. B. Browning.
185. Thanatopsis. Bryant.
186. The deserted village. Goldsmith.
187. Lochinvar. Scott.
188. The realm of fancy, Ode to melancholy, The eve of St. Agnes, etc., Keats.
189. The marriage of Heaven and Hell, etc. William Blake.
190. Rubaiyant of Omar Khayyam. Fitzgerald. Fifth edition.
191. Robyn Hode.
192. Elegy written in a country churchyard. Grey.
193. The song of Roland.
194. Hermann and Dorothea, etc. Goethe.
195. Cotter's Saturday night, etc. Robert Burns.
196. The sonnets. Shakespeare.
197. The raven, etc. Poe.
198. The torch bearers. Noyes.
199. Aeneid. Virgil.
200. The Iliad and the Odyssey. Homer.
201. The testaments of Francois Villon.
202. Figs from thistles, etc. Edna St. Vincent Millay.
203. John Brown's body. Benet.
204. The sunken bell. Hauptmann.
205. The cherry orchard. Tchekhov.
206. The doll's house. Ibsen.
207. Macbeth. Shakespeare.
208. Hamlet. Shakespeare.
209. Romeo and Juliet. Shakespeare.
210. Faust. Geothe.
211. Salome. Oscar Wilde.
212. The weavers. Hauptmann.
213. The father. Strindberg.
214. The life of man. Andreyev.
215. The daughter of Jorio. d'Annunzio.
216. The bonds of interest. Benavente.

217. Cyrano de Bergerac. Rostrand.
218. The tragical history of Dr. Faustus. Marlowe.
219. Wilhelm Tell. Schiller.
220. Manfred. Lord Byron.
221. The alchemist. Ben Johnson.
222. The school for scandal. Sheridan.
223. Prometheus bound. Aeschylus.
224. Mourning becomes Electra. O'Neill.
225. Plays, pleasant and unpleasant. Shaw.

EFFECT OF SOIL TREATMENT AND GRAZING MANAGEMENT ON THE PRODUCTIVITY, EROSION, AND RUN-OFF FROM PASTURE LAND[1]

C. A. VAN DOREN, W. L. BURLISON, L. E. GARD, AND R. F. FUELLEMAN[2]

THIS paper presents preliminary results of an experiment being conducted at the Dixon Springs Soil and Water Conservation Experiment Station, located in Pope County, Ill. The station is in the lower Mississippi loess area, comprising 10 to 12 million acres of land in Illinois, Indiana, Kentucky, Tennessee, Arkansas, and Missouri and characterized by silt loam soils badly leached and seriously eroded (1).[3] Existing grazing management and lack of soil improvement practices by farmers are contributing to further depletion of soils of the area.

The general productivity of soils in this area is low. The average yield of 28 crops of wheat on the Elizabethtown Experiment Field on untreated plots during the period 1936–39 was 4 bushels per acre (2). The Elizabethtown field is located on a similar soil type.

The field at Dixon Springs on which this study was established had been used for hay or pasture during the previous 25- or 30-year period. An occasional corn crop was grown on the field when the pasture vegetation became undesirable and badly infested with weeds. Soil tests which were made before treating the plots indicated a need for 3 to 4 tons of limestone. Available phosphate in the soil was low according to the field test.

The objectives as formulated for study are to determine the effect of two rates of grazing, moderate and intense, and the effect of soil treatment, limestone and phosphorus in combination as against no treatment, on water retention, erosion resistance, and forage values of an uncultivated plant cover.

METHODS

Four grazing plots, each ⅓ acre in size, have been established, all located on approximately an 8% slope with a southwest exposure. Records have been secured since the summer of 1938 from plots representing four different combinations of soil treatment and grazing management as indicated below.

Soil Treatment	Grazing Management	Plot No.
Lime, phosphate	Intensive	1
Lime, phosphate	Regulated	2
None	Intensive	3–4
None	Regulated	5

[1]This study is being conducted as a cooperative project between the Illinois Agricultural Experiment Station, Urbana, Ill., and the Soil Conservation Service, Office of Research. Received for publication August 12, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 887.

These plots were treated and seeded during September 1936. After the ground was plowed, fertilizers were applied and were then well mixed into the surface soil with a disc and a spike tooth harrow. Treated plots received limestone applied at the rate of 3½ tons per acre, rock phosphate at 1,000 pounds per acre, and 32% superphosphate at 300 pounds per acre. An additional application at the rate of 150 pounds per acre of 32% superphosphate, or its equivalent, was applied by top dressing in the spring of 1939.

A pasture seed mixture containing orchard grass, 5 pounds; Kentucky bluegrass, 2½ pounds; redtop, 4 pounds; timothy, 2 pounds; sweet clover, 2 pounds; and alsike clover, 1½ pounds per acre, was used in the fall. White clover, 2 pounds; sweet clover, 3 pounds; and Korean lespedeza, 5 pounds per acre were seeded in the spring.

Run-off plots 70 by 14 feet in size are located within each ⅓ acre grazing plot (Fig. 1). Wooden plot walls direct the run-off from the plot into measuring equipment which is located outside of and adjacent to the boundaries of the grazing unit. From the collecting trough at the lower end of the plot the water is carried through a 4-inch iron pipe to the measuring equipment. The type of silt box, screens, divisor unit, and tank used is shown in Fig. 2. The divisor unit has been described by Geib (3).

As soon as possible after each rain, the run-off was removed from silt boxes and tanks and weighed. Samples for dry matter determinations were taken in triplicate from both silt boxes and tanks.

Composition and density of vegetation were determined at intervals of 30 to 45 days throughout the 1938 and 1939 grazing seasons by the vertical point quadrat method. Twenty randomized readings of 10 points, totalling 200 readings, were made on each ⅓ acre plot in 1938, and similarly 40 readings of 10 points were made in the 1939 season.

Seasonal forage yields for 1939 were calculated on the basis of vegetation harvested from five wire-cage enclosures per plot. The type of cage used, which is 3 feet 4 inches on each side, is shown in Fig. 1. Sample areas were located by randomization and the cages were moved at intervals of from 30 to 45 days during favorable growing periods. The protected areas were clipped previous to each grazing period. At the end of the grazing period vegetation on the protected areas was harvested, as well as the vegetation on similar sized unprotected areas. Yields were expressed in pounds per acre of oven-dry forage.

Yearling ewes were used as grazing animals. Pasture days of grazing were recorded in 1938 and 1939. Amounts of gain or loss in weight of sheep also were determined in 1939. The two degrees of intensity of grazing were determined by the amount of cover available for consumption by livestock. The intensively grazed plots were pastured closely or severely throughout the season. The plots on which regulated grazing was practiced were grazed moderately and the vegetation was maintained at a height of approximately 3 to 4 inches.

RESULTS

FORAGE YIELDS AND COMPOSITION OF STANDS FOR 1939

Although these plots were seeded in 1936, installations for measuring soil and water losses were not completed until July, 1938; and sheep for grazing the plots were not available until the summer of 1938. The plots were cut for hay in 1937.

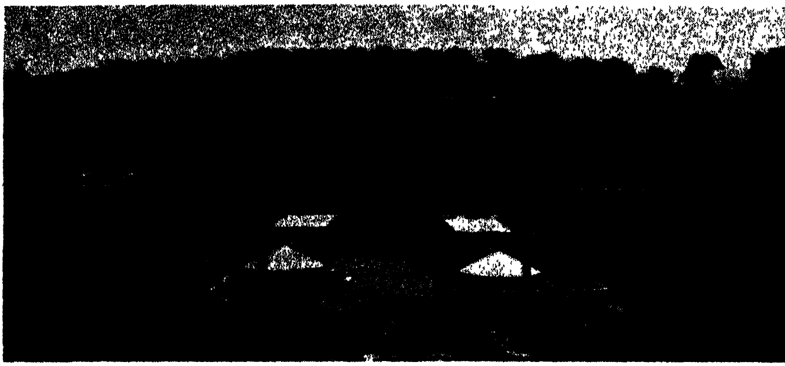

FIG. 1.—Run-off plots and measuring equipment for two 1/3 acre grazing areas. Plot 1, intensively grazed, in 1938; plot 2, grazing regulated. Photographed May 10, 1939.

The amount of vegetative cover on the treated land on which regulated grazing was practiced was from three to four times greater

FIG. 2.—Measuring equipment used for determination of soil and water losses from pastured plots. (1) Iron pipe, 4 inches in diameter, through which run-off flows from collecting trough at lower end of plot to silt box. (2) Silt box, 2 feet deep, 3 feet wide, and 6 feet long. These boxes have been lined with metal since photograph was taken. (3) Cover for silt box. (4) Screens for removing trash from run-off before entering divisor unit. The first or nearest screen has a 2-mesh wire cloth, the second has an 8-mesh wire cloth. (5) Multislot divisor unit. The five slots are each 4 inches high and 1/4 inch wide. (6) Small metal flume to carry run-off from center slot of divisor storage tank. Run-off from other four slots is discarded. (7) Metal storage tank, 4 1/2 feet in diameter and 4 feet high.

TABLE 1.—*Average yield of forage per acre, composition and density of vegetation as influenced by soil treatment and grazing management, Dixon Springs Soil and Water Conservation Experiment Station, 1939.**

Sample method	Plot 1, treated, intensively grazed			Plot 2, treated, regulated grazing			Plots 3–4, not treated, intensively grazed			Plot 5, not treated, regulated grazing		
	Apr. 26	June 26	Aug. 4	May 15§	June 26	Aug. 4	Apr. 26	June 26	Aug. 4	Apr. 26	June 26	Aug. 4
Protected areas, lbs.	674	1,322	1,340	1,383	1,557	603	322	1,316	945	—	1,713	632
Sum of protected areas, lbs.	674	1,996	3,336	1,383	2,940	3,543	322	1,638	2,583	—	1,713	2,345
Grazed areas, lbs†	—	535	792	—	2,092	2,204	—	357	1,196	—	—	1,882
Species‡												
Grasses:												
Bluegrass, %	9	6	4	13	13	7	4	1	0	2	0	Trace
Redtop, %	17	10	4	21	18	5	18	8	1	19	26	3
Timothy, %	13	4	1	15	5	0	2	Trace	0	4	Trace	0
Orchard grass, %	8	4	1	11	11	5	1	1	Trace	0	0	Trace
Legumes:												
Alfalfa, %	Trace	0	0	Trace	0	0	0	0	0	0	0	0
Alsike clover, %	0	0	0	0	0	0	0	0	0	0	0	0
White clover, %	1	2	1	1	1	1	0	1	0	0	0	0
Lespedeza, %	1	4	1	5	25	33	Trace	3	2	1	9	5
Sweet clover, %	0	0	0	0	1	0	0	0	0	0	0	0
Weeds, %	1	41	46	1	9	11	11	49	61	11	40	44
Bare ground, %	25	18	18	8	3	4	36	22	9	33	18	6
Dead vegetation, %	25	11	24	25	14	34	28	15	27	30	7	42

*Yield of forage is expressed as an average of five samples, each from an area 3 feet 4 inches square.
†Samples were taken at random from within the 1/8 acre grazed areas.
‡Percentages were obtained by taking 40 readings of 10 points each by point quadrat method.
§Vegetal data taken on April 26.

than on the land intensively grazed (Table 1). On June 26, on plot 1, intensively grazed, 535 pounds per acre were harvested as compared to 2,092 pounds per acre on plot 2, regulated grazing. On August 4, these same plots produced 792 pounds and 2,204 pounds, respectively (Fig. 3).

On land not treated, regulated grazing did not as markedly increase the amount of cover. On August 4, plots 3 and 4, intensively grazed, produced 1,196 pounds per acre as compared to 1,882 pounds per acre on plot 5, regulated grazing (Table 1).

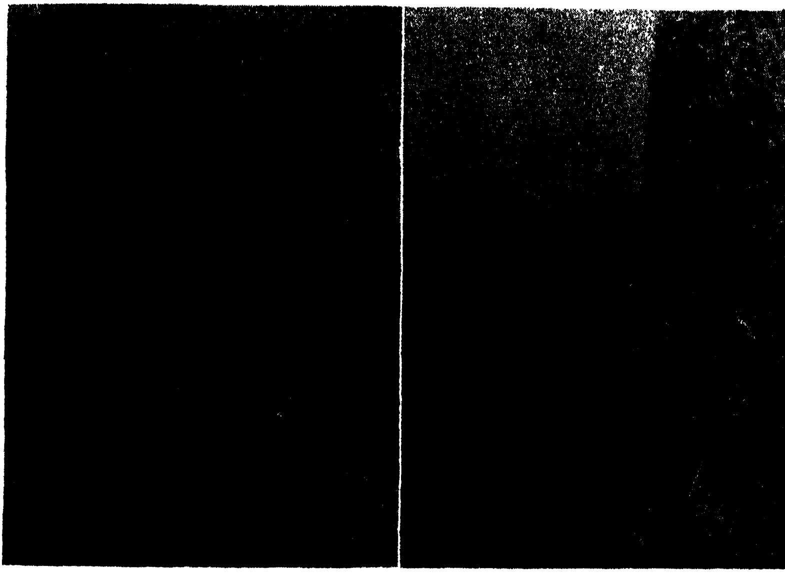

FIG. 3.—Effect of closeness of grazing on vegetation on treated plots. Photographed August 3, 1939. *Left*, plot 1, intensively grazed. Mostly weeds in stand. *Right*, plot 2, grazing regulated. Lespedeza and various desirable grasses in abundance.

Soil treatment increased the total seasonal production of dry forage per acre under intensive grazing. The total seasonal production in 1939 on plot 1, treated, was 3,336 pounds per acre, while on plots 3 and 4, not treated, the total seasonal production was 2,583 pounds (Table 1). With regulated grazing plot 2, treated, yielded 3,543 pounds per acre while plot 5, not treated, yielded 2,345. These results are more significant than indicated by the above figures as the plots which were not treated contained a considerably greater proportion of undesirable vegetation. On August 4, on plot 5, not treated, the vegetational cover contained 44% weeds as compared with only 11% on plot 2. The vegetational cover on the former plot contained only 8% of such desirable plants as lespedeza, bluegrass, redtop, orchard grass, and white clover while plot 2 had a total of 51% of these desirable plants.

RUN-OFF AND SOIL LOSSES

The average rainfall for a 44-year period (1895–1938) at New Burnside, Ill., approximately 12 miles northwest of the station, was 45.47 inches. Normal monthly rainfall in inches during this period was as follows:

Jan.	4.28	Apr.	4.31	July	3.53	Oct.	3.41
Feb.	2.78	May	4.11	Aug.	3.33	Nov.	3.51
Mar.	4.50	June	4.20	Sept.	3.61	Dec.	3.54

Monthly distribution during a given year may be extremely variable, however.

Some of the erosion stations have published data showing the small amount of soil and water lost from pasture land. Hays and Palmer (4) stated that bluegrass sod not mowed, that is, left to grow wild without cutting or pasturing, allowed an annual soil loss of only 0.03 ton and 2.8% run-off. They also reported that plots in grain in 1933 lost 1.6 times as much water as pasture plots; plots in hay in 1934 lost 1.3 times the water lost by the pasture plots; and the plots in corn in 1935 lost 3.0 times as much. Woodruff and Smith (5) reported low soil losses from several pastured areas. They reported that intensive grazing caused a significant increase in run-off as compared with moderate grazing. The vegetation on these plots differed considerably, however, from the vegetation on the Dixon Springs area.

During the 12-month period, July 1938 through June 1939, 37 run-off and soil loss records were obtained. A total of 72 rains causing run-off contributed to the results. Soil losses in pounds per acre from plot 2, which received limestone and phosphate, and on which grazing was moderate in 1938 and 1939, totalled only 330 pounds (table 2). Plot 1, which received limestone and phosphate and was intensively grazed, lost 4,378 pounds of soil per acre. Considering the severe grazing on this plot the total soil loss was small and it indicates the value of pasture vegetation in controlling soil erosion.

Soil losses were also small and were not significantly affected by grazing management on the untreated plots. The soil loss from plot 5, untreated with regulated grazing, was 1,671 pounds per acre which was within the limits of losses from plot 3, 1,292 pounds, and plot 4, 3,684 pounds, untreated with severe grazing. Plots 3 and 4 were both located within the same ⅓ acre grazing area, although plot 4 has slightly less surface soil remaining than plot 3.

Under intensive grazing, the plot which was treated with limestone and phosphate lost more soil per acre than the plot which was not treated, while the reverse was true with moderate grazing. Plots 3 and 4 with severe grazing, which were not treated, lost 1,292 and 3,684 pounds per acre, respectively, as compared with 4,378 pounds from plot 1 which was treated with limestone and phosphorus. This discrepancy was caused in part by the greater abundance of annual grass weeds, particularly the very unpalatable species of aristida on the plots not treated. The vegetal cover on grazing plots 3 and 4 contained 76% weeds and yielded 1,345 pounds per acre of dry forage on August 18, 1938; while that of plot 1, treated

with limestone and phosphate, contained only 42% weeds and yielded 1,180 pounds of dry forage. A year later on August 4, 1939, plots 3 and 4 again contained a larger percentage of weeds and produced a greater amount of dry matter than did plot 1. On the plots with moderate grazing, plot 5, untreated, lost 1,671 pounds while plot 2, treated, lost only 330 pounds of soil per acre.

On land treated with limestone and phosphorus, run-off losses during the 9 months, July through December 1938, and April through June 1939, from intensively grazed land were greater than from land on which grazing was moderate. Plot 1 which was intensively grazed lost 4.82 inches of water or 16.6% of the total precipitation, while plot 2 on which grazing was regulated lost only 0.74 inch of water or 2.6% of the total precipitation. (Table 2). Run-off records were obtained from 43 rains during the 9-month period, and in each instance the loss was greater from the intensively grazed plot. Losses during the 3 months, January to March 1939, were excluded, inasmuch as seepage prevented securing accurate records of run-off.

On the untreated plots, the water lost from plot 5, regulated grazing, 4.68 inches, was between the amount from the intensively grazed plots, plot 3, 3.24 inches, and plot 4, 6.31 inches.

Run-off losses from the untreated plot were greater than from the treated plot when the grazing on both plots was regulated. When intensive grazing was practiced on both treated and untreated plots, the run-off losses were not greater from the untreated land. Run-off plots 3 and 4 were located within the same grazing unit, untreated and intensively grazed. Plot 4 was about 100 feet farther up the slope and had slightly less surface soil remaining than plot 3. The run-off losses from plots 3 and 4 were 11.2 and 21.8% of total precipitation, respectively, as compared to 16.6% from plot 1 which was grazed similarly but which received an application of limestone and phosphorus. Intensive grazing on land not treated favored development of weedy grasses, especially aristida species, which were not eaten by sheep but which retarded soil and water losses.

SHEEP PRODUCTION

Approximately the same number of days grazing was obtained during the second season of grazing in 1939 on treated land when grazing was regulated (198 pasture days) as when intensive grazing was followed (202 pasture days). (See table 3.) A pasture day means the pasturing of one yearling ewe for one day. Considerably fewer days of grazing were obtained on untreated land under moderate grazing (112 pasture days) than under severe grazing management (182 pasture days).

Gain or loss in weights of sheep as well as total days of pasturage were obtained during the second season of grazing (1939). Yearling ewes on the treated plot where grazing was regulated produced a total of 68 pounds gain per ⅓ acre, while on the treated plot which was intensively grazed the ewes produced only 9 pounds of gain.

Regulation of grazing failed to bring about such satisfactory gains on untreated land. The sheep on the untreated, intensively grazed ⅓ acre plot lost a total of 13 pounds during the 182 pasture days of

TABLE 2.—*Run-off and soil loss in run-off from plots as influenced by soil treatment and grazing management, Dixon Springs Soil and Water Conservation Experiment Station, July 1938 to June 1939.*

Date	Rainfall						Plot 1, treated, intensively grazed		Plot 2, treated, regulated grazing		Plot 3, not treated, intensively grazed		Plot 4, not treated, intensively grazed		Plot 5, not treated, regulated grazing	
	Number of rains	Amount, in.	Duration, min.	Intensities per hour, in.			Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.	Run-off in % of rainfall, %	Soil loss per acre, lbs.
				5 min.	15 min.	30 min.										
							1938									
July 12	1	1.24	165	2.40	1.76	1.16	6.5	10	0.4	3	17.8	25	22.4	62	31.1	61
July 17	1	0.71	280	1.20	0.96	0.66	0.9	1	0	1	1.6	3	4.8	3	10.0	5
July 17, 18	4	1.37	435	3.60	2.88	1.52	20.1	28	6.9	20	33.7	64	44.2	65	41.8	91
July 31	1	0.95	450	0.36	0.24	0.24	1.7	1	1.4	1	0.5	1	3.0	1	8.6	2
Aug. 1	1	0.41	195	1.68	1.04	0.60	0.7	2	0	1	3.4	2	16.8	3	17.8	5
Sept. 10	1	1.13	22	4.56	4.32	—	15.9	15	0.8	2	22.5	30	42.7	49	23.3	20
Sept. 13	1	0.91	235	3.12	1.08	0.84	1.4	2	0.2	Trace	6.4	9	14.7	15	8.4	11
Oct. 20	1	1.15	420	2.16	1.12	0.76	0.2	Trace	0	0	0.4	Trace	0.3	Trace	1.3	1
Nov. 4	1	0.37	130	1.56	0.60	0.38	1.6	5	0.3	Trace	0.8	1	1.4	2	0.8	1
Nov. 7	1	0.60	105	1.68	1.12	0.58	8.7	37	1.0	2	10.2	13	20.5	31	18.2	23
Nov. 7	1	0.34	195	0.60	0.24	0.20	1.2	1	0	0	0.6	1	2.4	1	5.0	2
Nov. 18	1	1.70	473	4.32	1.52	0.78	26.3	527	3.2	21	22.5	82	50.7	257	27.4	121
Nov. 23	1	0.27	105	0.36	0.32	0.22	3.7	1	0	0	2.6	1	4.8	1	5.2	1

							1939									
Jan. 28, 29	2	1.08	195	0.48	0.32	0.28	0.5	1	0	0	0	0	0	0	0.6	1
Jan. 29, 30	2	2.21	1,015	0.72	0.52	0.46	102.5	475	18.3	44	91.0	258	91.6	331	96.8	237
Feb. 1, 2	3	1.52	890	0.72	0.48	0.40	143.4	276	21.1	31	96.1	108	165.1	251	125.0	144
Feb. 2, 3, 6, 9, 10	7*	2.55	935	2.28	0.88	0.58	129.4	542	23.1	50	118.8	213	238.8	641	156.1	248
Feb. 14	2*	0.82	430	0.24	0.20	0.18	90.0	24	8.4	1	9.4	2	44.8	26	39.6	9
Feb. 18, 19	2	1.44	650	0.96	0.72	0.64	197.4	588	21.8	22	75.1	84	122.7	311	120.7	153
Feb. 24, 25, 26	2*	0.68	30	—	—	—	150.0	22	0	0	4.9	1	44.7	14	40.4	6
Feb. 27	1*	0.78	—	—	—	—	211.9	351	25.1	10	52.1	25	97.1	216	114.4	110
March 4, 5	3	2.99	1,050	1.80	0.72	0.40	123.1	803	33.1	83	62.4	213	127.9	790	99.9	220
March 10	1	0.77	443	0.48	0.40	0.30	54.5	17	1.3	1	2.6	2	44.2	22	24.7	9
March 11, 12	4	0.49	215	1.20	0.52	0.34	169.4	41	8.2	1	14.3	2	124.5	38	63.3	12
April 5, 6	2	1.79	1,110	0.48	0.36	0.32	7.8	7	0	Trace	6.1	7	11.7	13	7.3	5
April 10	1	0.36	125	1.44	0.72	0.38	8.3	13	0	0	0	0	11.1	14	5.6	6
April 15, 16	3	1.97	445	2.04	1.04	0.96	95.9	205	19.3	18	36.0	39	58.4	157	60.9	75
April 16, 17	2	0.84	380	1.80	0.76	0.38	100.0	92	14.3	8	56.0	30	81.0	109	92.9	63
April 17, 18	3	0.17	265	0.24	0.12	0.06	64.7	4	0	0	0	0	29.4	2	82.4	3
April 20, 21	2	0.33	200	0.48	0.40	0.24	9.1	3	0	0	0	0	27.3	5	24.2	4
May 25	2	0.75	40	2.88	2.00	—	25.3	122	2.7	4	17.3	33	30.7	94	5.3	9
May 27	3	0.35	145	0.84	0.48	0.46	5.7	3	0	0	0	Trace	8.6	4	0	0
June 1	1	0.66	275	0.72	0.40	0.34	1.5	Trace	0	0	1.5	Trace	3.0	2	0	0
June 8, 9	3	0.60	298	1.08	0.52	0.28	1.7	1	0	0	0	Trace	1.7	2	0	0
June 10	1	0.35	30	2.16	1.20	0.68	25.7	41	0	0	17.1	11	34.3	44	5.7	4
June 19	3	0.48	70	1.80	0.72	0.18	6.3	13	0	0	4.2	3	12.5	14	0	0
June 20	1	0.76	60	1.92	1.84	1.00	43.4	104	3.9	6	32.9	29	50.0	94	15.8	9
Total soil loss and run-off per acre:																
For 12 months (July, 1938–June, 1939), lbs.							4,378		330		1,292		3,684		1,671	
Precipitation† and run-off, 9 months (July, 1938 through June, 1939, excluding Jan.–Mar., 1939):																
Total precipitation, inches							29.00		29.00		29.00		29.00		29.00	
Total precipitation (rains causing run-off), inches							20.56		20.56		20.56		20.56		20.56	
Total surface run-off, inches							4.82		.74		3.24		6.31		4.68	
Total surface run-off in % of precipitation, %							16.6		2.6		11.2		21.8		16.1	

*Snow and rain.
†Total precipitation for 12 months, July 1938 through June 1939 was 42.24 inches.

TABLE 3.—*Sheep gains or losses and pasture days of grazing on one-third acre areas.**

Plot No.	Treatment†	1938, pasture days	1939	
			Pasture days	Total gain or loss in weight of sheep, lbs.
1	Lime, phosphate; intensively grazed	335	202	+9
2	Lime, phosphate; regulated grazing	166	198	+68
3, 4	No soil treatment; intensively grazed	225	182	−13
5	No soil treatment; regulated grazing	83	112	+21

*A pasture day refers to pasturing of one yearling ewe for one day.
†Plots were treated and seeded in September 1936. The first season of grazing was during 1938.

grazing, while those on the untreated plot where grazing was regulated gained 21 pounds during 112 pasture days. In view of this small gain and only 112 pasture days of grazing, it is very doubtful whether production can be improved to any practical extent in humid areas by controlling grazing without soil treatment, particularly where initial fertility levels are low.

During the first season of grazing, land intensively or severely grazed furnished more pasture days of grazing than land on which grazing was well controlled or regulated. In 1938, 335 days of pasturage were obtained from the treated and intensively grazed ⅓ acre plot, while 166 pasture days were obtained from the treated plot on which grazing was regulated (Table 3). Plot 3 and 4, not treated but intensively grazed, furnished 225 pasture days while plot 5, untreated and on which grazing was regulated, furnished 83 pasture days. A decrease in pasture days of grazing was expected during the first season as the forage on plots to be severely grazed entered the season with root reserves equal to reserves on those which were to be moderately grazed.

SUMMARY

This paper presents the results of an experiment conducted at the Dixon Springs Experiment Station as a cooperative project between the Illinois Agricultural Experiment Station and the Soil Conservation Service, Research Division. The purpose of the experiment is to determine the effect of intense and moderate grazing and soil treatment on soil and water losses and forage values of pastures.

Four areas ⅓ acre in size were fenced and grazed with sheep. Small run-off plots 70 by 14 feet in size were located within the grazing areas and it was from these small plots that soil and water losses were measured. Intense and regulated grazing was practiced on both treated and untreated soil.

Forage yields and vegetal data were obtained by random sampling of small areas by the point quadrat method. Days of pasturage with yearling ewes are reported for 1938 and 1939. In 1939, pounds of gain or loss in weight of sheep are also given.

The amount of vegetative cover on treated land on which regulated grazing was practiced was from three to four times greater than

on land intensively grazed. Regulation of grazing did not markedly increase the amount of cover on untreated land. Severe grazing and lack of soil treatment increased the proportion of undesirable vegetation.

Soil losses from land with established vegetal cover, even under conditions of severe grazing management and low fertility, were very small. Annual weedy grasses which were abundant on untreated land under intensive grazing protected the soil against erosion.

Run-off losses from intensively grazed land that was treated with limestone and phosphorus were greater than from land similarly treated that was moderately grazed. On the untreated plots, grazing management did not significantly affect the run-off losses.

Under moderate grazing run-off losses from land untreated were greater than from land which was treated, but the losses were not greater under severe grazing. These results were influenced by the type of weed growth which is produced on untreated land.

Number of pasture days of grazing with sheep were approximately the same on treated land under the two intensities of grazing. On land not treated, fewer days of grazing were obtained under moderate than severe grazing management.

Yearling ewes gained considerably more during the grazing season on treated land when grazing was regulated than when grazing was severe.

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THE EFFECT OF SOIL CHARACTERISTICS AND WINTER LEGUMES ON THE LEACHING OF POTASSIUM BELOW THE 8-INCH DEPTH IN SOME ALABAMA SOILS[1]

N. J. VOLK[2]

A SOLUBLE salt added to the soil will leach into the subsoil as the drainage water moves downward unless something obstructs its passage. In the case of a soluble potassium salt, absorption by plants, soil flora, and exchange material will retard or inhibit the downward passage of the potassium. Truog and Jones[3] reviewed the literature and found that losses of potassium due to leaching varied between practically none and 70 pounds per acre annually, with an average of 10 to 15 pounds per acre per year.

It is the purpose of this paper to report the extent to which potassium has leached below a depth of 8 inches in 8 years when it was applied in varying amounts to different soils and under different cropping systems on fertility plots located on Alabama substations and experiment fields.

METHOD OF INVESTIGATION

Assuming that the greater portion of the potassium that leached below the 8-inch depth would be caught by the exchange material in the 8- to 24-inch depth, a study was made of the distribution of potassium in the soil profile to a depth of 24 inches before and after 8 years of cropping and fertilizing.

A total of 210 plots on eight different soil types were sampled at the 0- to 8-, 8- to 16-, and 16- to 24-inch depths in most cases. Each plot consisted of about 1/40 acre. In sampling a plot, soil was taken from 12 locations to form a composite sample. These samples were then analyzed for soluble and replaceable potash by leaching with ammonium acetate and precipitating the potassium as potassium sodium cobaltinitrite.

EFFECT OF SOIL TEXTURE AND AMOUNT OF POTASSIUM APPLIED PER ACRE ON AMOUNT OF POTASSIUM LEACHED BELOW THE 8-INCH DEPTH

The rates of potash tiers were sampled for this study. These tiers are located on three types of soil as follows: (1) Norfolk fine sandy loam having a friable sandy clay loam subsoil, (2) Hartsells very fine sandy loam having a friable sandy clay loam subsoil, and (3) Decatur clay having a compact but friable clay subsoil. These tiers were cropped continuously to cotton without summer or winter legumes. The amounts and kinds of fertilizer applied annually to the plots were 36 pounds of nitrogen as sodium nitrate, 60 pounds of P_2O_5 as superphosphate, and 0 to 80 pounds of potassium as the muriate.

From the results of the analyses given in Table 1 it is apparent that the nature of the soil has a definite influence on the amount of

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication September 9, 1940.

[2]Soil Chemist.

[3]TRUOG, E., and JONES, R. J. Ind. and Eng. Chem., 30:882–885. 1938.

potassium that is leached below the 8-inch depth. In the case of Norfolk fine sandy loam, about as much potassium leached into the 16- to 24-inch layer as leached into the 8- to 16-inch layer, a condition which indicates that a large amount of potassium may have passed below the 24-inch depth. On the other hand, most of the leached potassium was held in the 8- to 16-inch depth of the Hartsells very fine sandy loam, and practically none was leached below the 8-inch depth in the case of Decatur clay.

TABLE 1.—*The amounts of potassium leached below a depth of 8 inches in 8 years when various amounts of muriate of potash were applied to soils of different texture.*

Texture of the soil		Pounds of potassium applied per acre*		Pounds of potassium per acre that leached into and were retained by		Amount of potassium per acre that leached into and was retained by the 8 to 24 in. depth	
Surface	Subsoil	Annual application	Total applied in 8 years	The 8–16 in. depth	The 16–24 in. depth	Pounds per acre	Per cent of total potassium applied
			Norfolk				
Fine sandy loam	Sandy clay loam	10	80	5	2	7	9
		20	160	23	17	40	25
		40	320	49	43	92	29
		80	640	114	102	216	34
			Hartsells				
Very fine sandy loam	Sandy clay loam	10	80	7	2	9	11
		20	160	19	11	30	19
		40	320	38	26	64	20
		80	640	158	42	200	31
			Decatur				
Clay	Clay	10	80	0	0	0	0
		20	160	3	6	9	6
		40	320	12	11	23	7
		80	640	31	25	56	9

*Duplicate plots were installed for each treatment.

The amount of potassium that leached below the 8-inch depth was directly proportional to the amount of potassium applied.

Since the loss of potash through leaching is a factor of considerable importance as shown by these data, systems of cropping should be employed which will minimize this loss.

USE OF WINTER LEGUMES FOR PREVENTING LEACHING OF POTASSIUM

In another set of tiers of plots scattered over eight different soil types in the state, a winter legume was used in the rotation on some of the plots. This condition offered a chance to study the effect of winter legumes in conserving applied potassium. A total of 128 plots

which had received an average of 24 pounds of potassium annually or a total of 192 pounds in 8 years, were sampled at the 8- to 24-inch depth and analyses were made for replaceable and soluble potassium.

The data in Table 2 show that winter legumes were very effective in preventing leaching of potassium below the 8-inch depth. The percentage of applied potassium lost was reduced from 20.2% to 3.1%.

TABLE 2.—*The amounts of potassium leached into the subsoil when winter legumes were or were not present in the rotation.*

Soil*			Percentage of applied potassium that leached into the 8–24 in. layer of the subsoil in 8 years		Percentage of potassium applied that was prevented from leaching by being absorbed by the legumes
Series	Texture of surface	Texture of subsoil	No winter legumes in the rotation	Winter legumes in the rotation	
Kalmia	Very fine sandy loam	Clay	8.9	2.7	6.2
Greenville	Clay	Clay	12.2	2.7	9.5
Hartsells	Very fine sandy loam	Sandy clay loam	18.1	0	18.1
Decatur	Clay	Clay	19.9	3.8	16.1
Orangeburg	Fine sandy loam	Clay	21.1	6.4	14.7
Decatur (eroded)	Clay	Clay	23.0	3.4	19.6
Norfolk	Sandy loam	Sandy loam	26.1†	4.2	21.9
Norfolk	Fine sandy loam	Sandy clay loam	32.1	1.9	30.2
Average			20.2	3.1	17.1

*The number of fertility plots investigated ranged between 12 and 38 for each soil type.
†Analyses of the 8- to 16- and the 18- to 24-inch depths indicated that a large amount of potassium leached even below the 24-inch depth in this soil due to the very sandy nature of the subsoil.

DISCUSSION AND SUMMARY

From the results of this investigation, it is apparent that the leaching of potassium below the 8-inch depth is a factor of major importance in certain of the more sandy soils of Alabama. The texture of the soil and the type of plants grown will, of course, cause great differences in the amount of potassium that is leached downward. The data show that when no winter legumes were grown, the amount of potassium leached into the 8- to 24-inch layer and retained there over an 8-year period amounted to from 9 to 32% of the amount added. On the other hand, when winter legumes were grown, the amount of potassium leached was from 0 to 6% of the amount added. The potassium saved through winter legumes amounted to about 17% of the total potassium applied.

Winter legumes, therefore, in addition to aiding in the prevention of soil erosion and to supplying nitrogen to the succeeding crops, are important from the standpoint of conserving soil potassium.

VIABILITY OF BUFFALO GRASS SEEDS FOUND IN THE WALLS OF A SOD HOUSE[1]

ALVIN E. LOWE[2]

A NUMBER of well-preserved burs of buffalo grass (*Buchloë dactyloides* Nutt.) were found during November, 1939, in the broken portions of the walls of a sod house located in Greeley County, Kansas. The walls were built of sod blocks laid up in the manner of bricks, except no mortar was used. The sod blocks were about 18 inches square and 4 inches thick. The grassy side of the sod was turned down so it could be shaved to a uniform thickness with a spade and a neater and more nearly plumb wall made. The inside walls were plastered with lime and the nearly flat roof was of wooden planks covered with tar paper. The walls were unprotected on the outside and no foundation of any sort had been used.

The grass in these walls was well preserved except for a few inches at the outside edges of the sods, evidently where rainwater had penetrated and discolored it. In the center of the walls the grass was bright in color and formed a thick mat, as shown in Fig. 1. Some of

FIG. 1.—Small buffalo grass sod at left is from walls of rooms built 35 years ago. The large sod at the right is from wall of room built 25 years ago. Note bur lying as found near the two on the 6-inch rule. ×⅝.

[1]Contribution No. 68, Office of the Director, Kansas Agricultural Experiment Station, Manhattan, Kans. Received for publication September 19, 1940.

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the leaves and stolens of the 25-year-old sod still had a light green color. The sods were full of strong roots which held them together. The sod was nearly all buffalo grass with a small quantity of blue grama (*Bouteloua gracilis* H. C. K.) and a few small unidentified herbaceous plants.

The buffalo grass burs were nearly all found under the grass leaves and in shallow depressions which were probably hoof marks of animals that had grazed on the grass. The burs appeared so well preserved (Fig. 2) that it was decided to see if any of the caryopses were viable. Lacking proper facilities at this station for testing germination, 18 burs from the outside walls of the room constructed in 1915 were given to Mr. D. A. Savage, Agronomist, Division of Forage Crops and Diseases, Southern Great Plains Field Station, Woodward, Oklahoma. From these 18 burs, 20 caryopses were obtained and planted in individual paper pots at a depth of ½ inch in sterilized soil. They were watered with distilled water and kept in a greenhouse. From these 20 caryopses which were 25 years old, 3 seedling plants of buffalo grass were obtained. These data are presented in Table 1.

TABLE 1.—*The age, number and percentage of viable buffalo grass caryopses found in the walls of a sod house.*

Germination test method	Age in years	Number			Percentage viable
		Burs	Caryopses	Viable	
Soil in greenhouse at Woodward, Okla.	25	18	20	3	15
Seed germinator at Manhattan (1st test)	25	19	14	11	78
Seed germinator at Manhattan (2nd test)	25	32	40	7	18
Total		69	74	21	28
Seed germinator at Manhattan	35	93	50	0	0

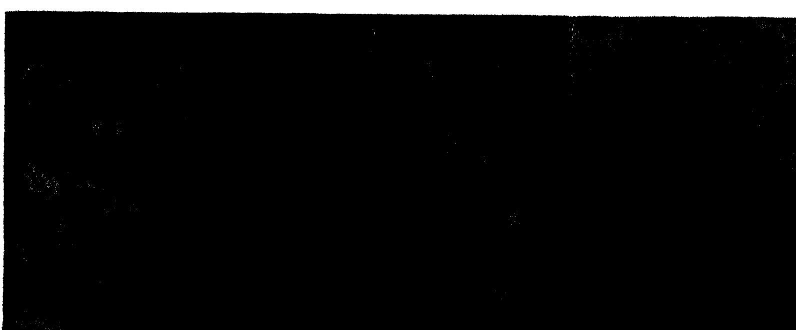

FIG. 2.—Buffalo grass burs at left of rule are from sod 25 years old, those to the right are 1 year old, and those at the extreme right are 35 years old with the dark colored ones placed on a light background. ×1.

Fearing some unforeseen accident might cause a complete loss if all the burs were tested by one method at the same time and place, 19 of them were given to Mr. Kling L. Anderson, Assistant Professor of Pasture Management, Agronomy Department, Kansas State College, Manhattan, Kansas. From these 19 burs 14 caryopses were obtained and these were placed on moist filter papers in Petri dishes and germinated according to regular seed laboratory practices. Eleven of the 14 caryopses germinated and were transplanted to pots in the greenhouse.

Later, another group of 32 burs from walls of the room constructed in 1915 was tested by Mr. Anderson. In these 32 burs there were 40 caryopses of which 7 germinated and were transplanted to pots in the greenhouse.

From the walls of the two rooms built in 1905, 93 burs were obtained. These contained 50 caryopses which were apparently in a fairly good state of preservation. Only a few of these 35-year-old burs looked bright and fresh; many were slightly discolored and a few were dark colored and crumbled under slight pressure. These burs are shown in Fig. 2. None of these 35-year-old caryopses germinated when placed on moist filter papers in Petri dishes and tested under regular seed laboratory procedure.

In this article the author has stated the age of the buffalo grass burs as being the same as that of the walls from which they were removed, but the possibility of a portion or all of them having been produced in years previous to the construction of the walls should not be overlooked.

The 21 buffalo grass plants secured are being grown in greenhouses at Manhattan and Woodward. Those that survive will be set in the field so they can be compared with buffalo grass that has been growing and therefore subjected to environmental selection during this 25-year period.

"MILORGANITE" AS A SOURCE OF MINOR NUTRIENT ELEMENTS FOR PLANTS[1]

C. J. REHLING AND EMIL TRUOG[2]

DRIED activated sludge is produced at the rate of over 100 tons daily at the Milwaukee Sewage Disposal Plant and sold under the trade name of "Milorganite". Results have been obtained from the use of this fertilizer which indicate appreciable benefits from constituents other than the nitrogen and available phosphoric acid contents of 6 and 2.5 per cent respectively. These results have been noted especially on very sandy soils, particularly in the Southeast where striking benefits from the use of boron, copper, manganese, and zinc have been reported. It was therefore believed that these minor nutrient elements might account, at least in part, for some of the favorable effects produced by Milorganite.

An extended analytical study of Milorganite (31)[3] revealed the presence of some twenty-three elements, a number of which can serve as plant nutrients. Significant amounts of boron, copper, manganese, and zinc were found to be present in an available form as determined by extraction with a solution of carbonic acid. The importance of these elements in plant nutrition is now generally recognized (38). The experiments described in this paper were carried out to determine if Milorganite could supply the minor nutrient elements required by plants.

NEED OF MINOR NUTRIENT ELEMENTS

Boron.—That boron is essential was demonstrated by McHargue and Calfee (24) for lettuce; by Ferguson (13) for cauliflower; by Askew and Chittenden (4) for apples; by van Schreven (37) for tomatoes; by Purvis and Ruprecht (30) for celery; by McMurtrey (26) for tobacco; and by Foex and Burgevin (14) for sugar beets. The occurrence of boron deficiency in the soils of the Coastal Plain and other areas has been reported by Willis and Piland (39), Naftel (29), McHargue and Calfee (25), and others.

The symptoms of boron deficiency usually reported are distorted leaves, depressed growth, and death of terminal buds. A breakdown of meristematic tissue and serious interference with translocation probably accounts for the observed increase in starch and sugar contents of leaves of plants which are not supplied with boron.

Copper.—Increased productivity of peat and muck soils from the addition of copper has been reported by Allison, *et al.* (1), Felix (12), Harmer (18), and others.

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[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. and published with the permission of the Director of the Wisconsin Agricultural Experiment Station. This paper represents, in part, thesis material submitted by the senior author to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. The work here presented was supported in part by a fellowship grant from the Milwaukee Sewerage Commission, Milwaukee, Wis. Received for publication September 23, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 905.

More recently, however, benefits have been reported from the use of copper on mineral soils by Andersen (2), Churchman, *et al.* (9), Hill and Bryan (19), and others.

Copper seems to be necessary in very small amounts for normal growth, chlorophyll formation, and seed production in plants, as was demonstrated by Sommer (35) and Lipman and Mackinney (21). Chlorotic spotting of leaves, curling or "frenching", and death of young shoots or branches are some of the symptoms usually associated with a deficient supply of copper, particularly in fruit and citrus trees. Stunted growth is the commonly reported symptom in the grasses and most crop plants.

Manganese.—McHargue (22), Haas (17), and others have shown that many crop plants fail to grow normally if manganese is excluded from the nutrient supply. That manganese is frequently lacking in soils was reported by Gilbert (16), Conner (11), Miller (27), Schreiner and Dawson (32), McHargue and Shedd (23), and many others. Gaddum and Rogers (15) report the presence of small amounts of manganese in a number of the common fertilizer materials.

Molybdenum.—It is only recently that attention has been directed to the presence and importance of molybdenum in plants, and very little information is available. Ter Meulen and Ravensway (36) found molybdenum in many kinds of leaves which they examined. Arnon (3) reported additional growth of plants after adding molybdenum, together with several other elements, to an otherwise complete culture solution. Hoagland and Arnon (20) obtained definite chlorotic symptoms in tomatoes by growing the plants in cultures lacking in molybdenum.

Zinc.—That zinc is essential for higher plants was emphasized by the solution culture work of Sommer (34). The use of zinc as a specific corrective for certain abnormalities has been reported by Mowry and Camp (28) for tung trees; by Barnette and Warner (5) for corn; by Chandler, *et al.* (7) for fruit trees; by Chapman, *et al.* (8) for citrus; and by Cole, *et al.* (10) for pecan trees.

The symptoms associated with a deficiency of zinc are chlorosis and stunted growth which in severe cases are followed by death of the affected parts or even of the entire plant. Frenching and rosetting of growing tips are frequently observed symptoms in fruit and citrus trees.

CORN EXPERIMENT

From earlier studies (31) it was found that Milorganite contained 0.0115% B_2O_3, 0.0431% CuO, 0.0250% MnO, and 0.030% ZnO. The following amounts were found to be readily available as determined by extraction with carbonated water: 0.0035% CuO, 0.0062% MnO, and 0.026% ZnO. Water-soluble boron was found to be present to the extent of 0.0073% B_2O_3. In order to check further the ability of Milorganite to furnish minor nutrient elements to plants, solution cultures were set up to some of which a carbonic acid extract of Milorganite was added as the only source of these minor elements.

PLAN OF SOLUTION CULTURES

Duplicate series of cultures were prepared. Each series included a control culture with complete nutrient medium and cultures from which were omitted either copper, manganese, or zinc, both singly or in combination. Boron was supplied to all cultures in this experiment.

The following salts were added in amounts indicated as basal nutrients to each culture:

KH_2PO_4 ....0.362 gram per liter
$Ca(NO_3)_2.4H_2O$ ....0.486 gram per liter
$MgSO_4.7H_2O$ ....0.250 gram per liter
NaI ....0.00025 gram per liter

Where the minor nutrient elements were added, the following amounts were supplied whether singly or in combination:

H_3BO_3 ....0.0028 gram per liter, equivalent to 0.50 p.p.m. boron
$CuSO_4.5H_2O$ ....0.0002 gram per liter, equivalent to 0.05 p.p.m. copper
$MnSO_4.4H_2O$ .. ....0.0021 gram per liter, equivalent to 0.50 p.p.m. manganese
$Zn(C_2H_3O_2)_2.2H_2O$ ..0.0017 gram per liter, equivalent to 0.05 p.p.m. zinc

The concentration of copper was later lowered to 0.02 p.p.m. since 0.05 p.p.m. appeared to be slightly toxic as indicated by comparison with plants of the control cultures. Iron was supplied when needed as ferrous sulfate which was prepared from pure iron wire. All salts used in this and the following experiments were of analytical reagent grade and were not further purified or tested for the minor nutrient elements; however, the physiological tests made later indicated a high degree of purity in this respect.

For containers, quart Mason jars were darkened with heavy paper and provided with paraffined corks. To minimize contamination by dust, the cultures were housed in a cellophane enclosure built upon a greenhouse bench. A double thickness of gauze toweling replaced a portion of the cellophane on one side of the enclosure to provide ventilation and access to the plants.

Two seedlings of yellow corn were transferred to each culture on February 2, 1939. Beginning with once a week, the nutrient solutions were thereafter renewed with increasing frequency as the plants grew, so that during the last week or more just prior to harvesting, renewals were made every other day.

On March 8, and with each solution renewal thereafter, 100-cc portions of a carbonic acid extract of Milorganite were added to each jar of one series of treatments including a control. This extract was prepared as needed by shaking 10 grams of Milorganite with 1 liter of carbonated water (pH 4.5) for 24 hours and filtering. Each 100 cc of this extract represented, as determined by analyses (31), an addition of 0.028 mgm of copper, 0.048 mgm of manganese, and 0.21 mgm of zinc. Beneficial effects from this extract were evident after about 5 days, and the marked improvement in appearance and growth of the plants continued until they were harvested.

The plants, both tops and roots, were harvested on March 25. Copper and manganese were determined in the dried plants by the colorimetric xanthate and periodate methods, respectively, while zinc was determined by the nephelometric ferrocyanide method (33).

RESULTS

Very characteristic deficiency symptoms developed where zinc was omitted from the cultures. Stiff, straight, and narrow leaves resulted which tended to fold together upwards along the middle rib. Their color was of a gray-green shade and translucent areas appeared at the leaf ends. The younger, emerging leaves were increasingly affected with chlorosis, and large, white areas were evident where chlorophyll was practically absent.

The lack of manganese caused a weak and characteristically chlorotic condition which lacked rigidity. Similar symptoms developed where copper and zinc were omitted from the nutrient solution.

About March 13 certain abnormalities became noticeable in the plants growing without added copper. Chlorotic stripes appeared in the younger leaves and the upper internodes remained very short. This condition became progressively more pronounced, while one plant grew an abnormal tip from this stunted region. These symptoms never appeared in the duplicate culture which received Milorganite extract.

Table 1 gives the dry weights and minor element content of the corn plants. In general, the amounts of copper, manganese, and zinc in the plants are closely correlated with the amounts of growth expressed by the dry weights. In every instance where a minor element deficiency existed and Milorganite extract was later added, increased yields resulted which are attributed to correction of the deficiency by the minor elements contained in the extract.

SUNFLOWER EXPERIMENT

The favorable results of the first experiment prompted a second experiment with solution cultures of sunflower under more carefully controlled conditions. Molybdenum was included among the minor nutrient elements studied.

PLAN OF SOLUTION CULTURES

Two series of cultures were included as in the experiment with corn. Treatments in each series included controls receiving all nutrient elements and cultures deficient in all or one of the minor elements boron, copper, manganese, molybdenum, and zinc. A carbonic acid extract of Milorganite was added to one series after the first week.

Instead of Mason jars, liter Pyrex beakers were used for containers as recommended by other workers (34). Where boron was the particular element under consideration, half-gallon Mason jars were cut to approximate the beakers in capacity and were substituted for the Pyrex beakers. Covers were molded from plaster of paris and paraffined for the protection of solutions and plants. The water used was distilled from glass containers.

Basal nutrients, similar as regards kinds and amounts used in the first experiment, were again added.

Minor nutrient element additions were the same as in the corn experiment with the following changes and additions:

$CuSO_4.5H_2O$ changed to 0.0001 gram per liter, equivalent to 0.02 p.p.m. copper

$H_2MoO_4.H_2O$ added at the rate of 0.00005 gram per liter, equivalent to 0.02 p.p.m. molybdenum

Sunflower seeds were germinated in acid-washed sand and two seedlings were transferred to each culture on March 23.

On March 29, when the solutions were renewed, a 100-cc portion of Milorganite extract, prepared as already described, was added to each culture of one series. This addition was repeated with each subsequent renewal of the solutions until the plants were harvested on April 21.

TABLE 1.—*Growth and minor element content of corn plants as influenced by adding minor elements and Milorganite extract to basal culture solution, the Milorganite extract being added only during last third of growth period.*

Addition to basal culture solution*	Dry weight of tops and roots (2 plants), grams	Content of two plants					
		Copper		Manganese		Zinc	
		Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.
1. Minor elements	28.87	0.980	34	11.3	400	3.26	113
2. Minor elements + Milorganite extract	26.37	1.530	58	13.0	490	3.30	125
3. Boron	0.32	0.013	41	0.0	0	0.03	94
4. Boron and Milorganite extract	1.39	0.040	29	Trace	0	0.29	206
5. Minor elements lacking copper	29.87	0.41	14	14.6	490	4.20	140
6. Minor elements lacking copper + Milorganite extract	33.20	1.19	36	11.0	330	5.80	175
7. Minor elements lacking manganese	0.85	0.09	106	0.0	0	0.31	364
8. Minor elements lacking manganese + Milorganite extract	2.67	0.17	64	0.0	0	0.37	140
9. Minor elements lacking zinc	3.82	0.25	66	3.8	1,000	0.09	24
10. Minor elements lacking zinc + Milorganite extract	5.21	0.43	84	4.6	880	0.81	155

*Basal culture solution contained all of the major nutrients, and minor elements consisted of boron, copper, manganese, and zinc.

Analyses of the total dry tissue (tops and roots) in each case were made for copper, manganese, and zinc by the methods used in the first experiment. Boron was determined in all samples by the colorimetric quinalizarine method (33). No attempt was made to determine molybdenum due to lack of sufficient plant tissue.

RESULTS

Significant differences in appearance of the plants were evident after about 2 weeks growth. Excepting the control, the plants receiving Milorganite extract were much superior in size and appearance to their respective duplicates in other series which were not receiving the extract. These differences became increasingly prominent up to the time of harvest. The lack of manganese gave rise to a characteristic, patterned chlorosis of the leaves and to severely retarded growth. The lack of boron caused the most noticeable effect, the plants having never produced true leaves and being dead at harvest. Retarded growth, together with sudden yellowing and death of the leaves, was associated with a deficient supply of zinc. The lack of molybdenum merely retarded growth without any noticeable chlorosis, and similar results were observed in the case of copper deficiency.

The effect of adding Milorganite extract was striking in all cultures otherwise deficient in one or more of the minor nutrient elements. Although the amounts of growth were not identical throughout the series receiving the extract, large increases due to this addition were apparent and are illustrated in Figs. 1 and 2. Growth differences associated with the addition of the extract to the control cultures receiving a complete nutrient solution were negligible.

Further expression is given to these observations through the dry weights and minor element contents of the plants given in Table 2. The correlation between yield and content of each of the minor elements is generally quite close. Milorganite extract increased the total amount of each of these elements in the plants. A deficient supply of molybdenum definitely lowered the yield of dry tissue.

TOMATO EXPERIMENT

Since tomato plants are known to require considerable amounts of the minor nutrient elements for normal growth, a further experiment was conducted with this plant.

PLAN OF CULTURES

This experiment with tomatoes was planned and executed in all respects as was the experiment with sunflowers, including the specific treatments.

The tomato plants (Earliana) were transferred to the culture solutions as seedlings on March 22, and the addition of Milorganite extract to one series was started at the time of renewing the solutions on March 29. Due to the slower growth of tomatoes, these cultures were continued for a longer period than the sunflowers and were harvested on April 29.

Analyses for boron, copper, manganese, and zinc were made by the same procedures as for the sunflower.

TABLE 2.—*Growth and minor element content of sunflower plants as influenced by adding minor elements and Milorganite extract to basal culture solution, Milorganite extract being added during last 3 weeks of 4-week growth period.*

Addition to basal culture solution*	Dry weight of tops and roots (2 plants), grams	Content of two plants							
		Boron		Copper		Manganese		Zinc	
		Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.
1. Minor elements	5.65	0.40	71	0.23	41	0.52	92	0.57	100
2. Minor elements + Milorganite extract	6.77	0.50	74	0.56	83	0.60	89	0.78	108
3. No addition	0.40	0.05	120	0.02	60	0.00	0	0.00	0
4. Milorganite extract	2.15	0.11	51	0.22	102	0.08	35	0.15	71
5. Minor elements lacking copper	3.63	0.30	84	0.02	6	0.25	68	0.37	102
6. Minor elements lacking copper + Milorganite extract	6.52	0.52	78	0.19	30	0.42	64	0.60	92
7. Minor elements lacking manganese	0.77	0.11	140	0.06	73	0.00	0	0.14	180
8. Minor elements lacking manganese + Milorganite extract	4.39	0.40	91	0.31	70	0.18	41	0.50	113
9. Minor elements lacking zinc	2.15	0.19	89	0.10	47	0.30	140	0.02	9
10. Minor elements lacking zinc + Milorganite extract	5.37	0.43	80	0.29	53	0.53	98	0.46	85
11. Minor elements lacking boron	0.25	0.01	40	0 06	260	0.01	44	0.04	145
12. Minor elements lacking boron + Milorganite extract	3.21	0.19	59	0.29	93	0.37	115	0.40	126
13. Minor elements lacking molybdenum	3.98	0.25	63	0.35	89	0.20	50	0.40	100
14. Minor elements lacking molybdenum + Milorganite extract	5.22	0.36	68	0.37	71	0.42	80	0.62	118

*Basal culture solution contained all of the major nutrients, and minor elements consisted of boron, copper, manganese, molybdenum, and zinc.

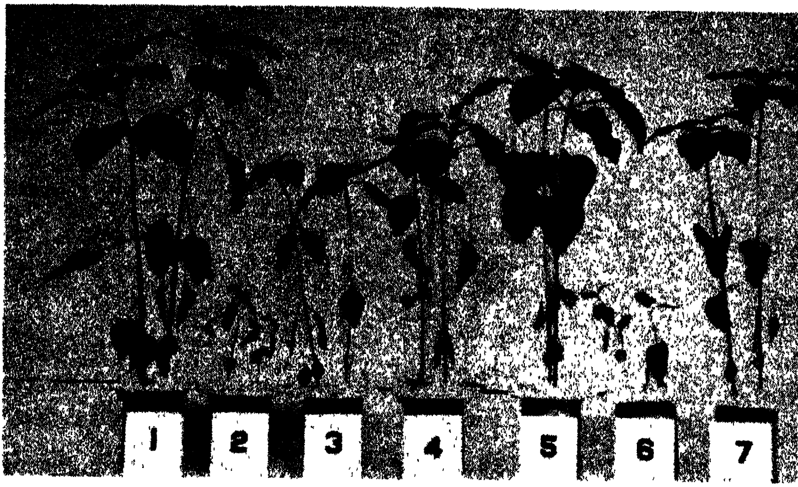

FIG. 1.—Effect of minor nutrient elements and Milorganite extract on the growth of sunflowers in culture solutions. Milorganite extract added only during last 3 weeks of the 4-week growth period. 1, control, all basal and minor nutrients supplied; 2, basal nutrients only; 3, basal nutrients+Milorganite extract; 4, basal nutrients+minor elements lacking copper; 5, basal nutrients+minor elements lacking copper+Milorganite extract; 6, basal nutrients+minor elements lacking manganese; and 7, basal nutrients+minor elements lacking manganese+Milorganite extract.

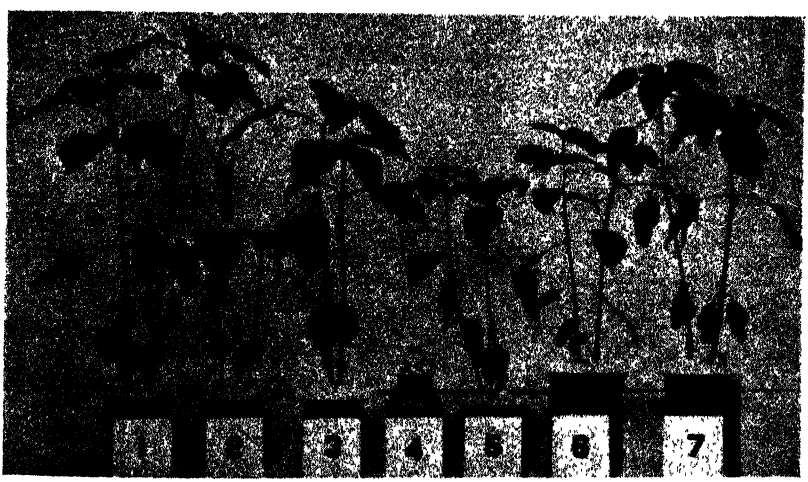

FIG. 2.—Effect of minor nutrient elements and Milorganite extract on the growth of sunflowers in culture solutions. Milorganite extract added only during last 3 weeks of the 4-week growth period. 1, control, all basal and minor nutrients supplied; 2, basal nutrients+minor elements lacking zinc; 3, basal nutrients+minor elements lacking zinc+Milorganite extract; 4, basal nutrients+minor elements lacking boron; 5, basal nutrients+minor elements lacking boron+Milorganite extract; 6, basal nutrients+minor elements lacking molybdenum; and 7, basal nutrients+minor elements lacking molybdenum+Milorganite extract.

RESULTS

Much of what was stated in describing the deficiency symptoms and growth of the sunflowers appropriately describes the results obtained with tomatoes. At harvest, many of the leaves of the manganese- and zinc-deficient plants were dying rapidly from the tips and edges. The symptoms of copper and molybdenum deficiencies were similar to but not as acute as those described by Hoagland and Arnon (20). Molybdenum deficiency appeared as a mild but general chlorosis which developed into a spotted pattern as the leaves approached full size. A leaf so affected bore some resemblance to one showing a mild manganese deficiency. Distorted growing tips and stunted growth characterized the plants which were deficient in boron.

At no time did the tomato plants which received Milorganite extract exhibit symptoms of minor element deficiencies. They appeared quite normal, although the amount of growth was generally not the equal of that made by controls, due probably to the addition of insufficient extract.

The yields and results of analyses of the tomato plants are given in Table 3. As with corn and sunflowers, the yields are closely related to the amounts of minor nutrient elements contained in the plants. The boron contents of Nos. 3 and 7, expressed as p.p.m., are irregularly high. Similarly, the manganese content of No. 9 and the zinc content of No. 11 are out of line, but these irregularities occurred in cases of severely retarded growth. Increases in the minor element contents and yields are associated with the addition of Milorganite extract to the cultures, other than the controls.

DISCUSSION

If ordinary precautions are observed, culture solutions may be quite readily prepared which are sufficiently free of the elements boron, copper, manganese, and zinc, respectively, so that little plant growth will occur.

A deficiency of boron permits of practically no growth in sunflower and tomato and finally specific disorders develop in the meristematic tissues which result in death of the plant. Chlorosis and the lack of structural rigidity, as observed in corn, sunflower, and tomato, indicates that a deficiency of manganese causes acute disturbance of general plant metabolism. Though required in smaller amounts than manganese, zinc seems to play an equally important role in plant life, since a deficient supply permits of little growth and causes a chlorosis which is followed by death of the leaves or of the entire plant. The symptoms of zinc deficiency in sunflowers agree closely with those described by Sommer (34).

Due in part to the very small amounts of copper required by plants for normal growth and in part to the difficulty of eliminating the last traces of this element from the nutrient medium, the development of severe deficiency symptoms was not as striking as with the other elements. Traces of copper were evidently contained in the nutrient salts used, since the tissue analyses revealed the presence of small amounts in all of the plants which were grown without

TABLE 3.—*Growth and minor element content of tomato plants as influenced by adding minor elements and Milorganite extract to basal culture solution, Milorganite extract being added during last 4 weeks of 5-week growth period.*

Addition to basal culture solution*	Dry weight of tops and roots (2 plants), grams	Content of two plants							
		Boron		Copper		Manganese		Zinc	
		Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.	Mgms	P.p.m.
1. Minor elements	9.25	0.56	60	0.26	28	1.45	156	1.00	108
2. Minor elements + Milorganite extract	8.77	0.60	69	0.34	39	1.98	230	1.23	141
3. No addition	0.20	0.07	350	0.04	200	0.00	0	0.00	0
4. Milorganite extract	5.65	0.16	28	0.18	32	0.45	80	0.46	82
5. Minor elements lacking copper	2.83	0.18	63	0.06	21	0.36	127	0.28	100
6. Minor elements lacking copper + Milorganite extract	5.25	0.19	36	0.21	40	0.87	165	0.62	118
7. Minor elements lacking manganese	0.52	0.09	170	0.05	96	0.00	0	0.74	142
8. Minor elements lacking manganese + Milorganite extract	4.27†	0.27	63	0.14	33	0.38	90	0.55	130
9. Minor elements lacking zinc	0.88	0.08	91	0.05	57	0.31	350	0.01	11
10. Minor elements lacking zinc + Milorganite extract	2.74	0.18	64	0.12	44	0.41	150	0.21	77
11. Minor elements lacking boron	0.23	Trace	—	0.07	31	0.40	174	0.05	208
12. Minor elements lacking boron + Milorganite extract	2.39	0.12	50	0.09	37	0.39	162	0.73	153
13. Minor elements lacking molybdenum	4.59	0.26	55	0.13	28	0.41	88	0.41	89
14. Minor elements lacking molybdenum + Milorganite extract	3.82	0.26	68	0.18	47	0.34	90	0.52	137

*Basal culture solution contained all of the major nutrients, and minor elements consisted of boron, copper, manganese, molybdenum, and zinc.
†One plant only.

intentional additions of this element. These amounts, however, were insufficient for maximum growth, and the results agree with those of numerous workers which indicate that copper is essential for plant growth.

Molybdenum seems to play an important role in plant growth as is evidenced by the reduced dry weight of sunflower and the chlorotic disorder noted in tomatoes when it was not added. The latter result agrees with the symptoms of molybdenum deficiency in tomatoes reported by Hoagland and Arnon (20).

The dry weights of the plants in each experiment are rather well correlated with the amounts of each of the minor nutrient elements found in the plants. Certain anomalies, which occurred in those instances of very low yields, are perhaps due in part to analytical errors such as may result when the amounts of tissue available for analysis are limited. The contents of B, Cu, Mn, and Zn found in the tomato and sunflower tissue indicate that a deficient supply of any one of these nutrient elements will result in the accumulation of a higher content of the others in the plant. A similar conclusion may be reached from the results with corn. The results obtained with molybdenum in the tomato and sunflower experiments show that Milorganite contains traces of this element in available form.

The results in general demonstrate that Milorganite can serve as a satisfactory source of the several minor nutrient elements for plant growth. The recovery made by corn after the addition of Milorganite extract from each of the several deficiencies would undoubtedly have been more striking if the experiment could have been continued for a longer period. Where Milorganite extract served as the only source of one or more of the minor nutrient elements for tomatoes and sunflowers, the growth approached but did not attain that of the controls. This is no doubt due largely to the interval of 1 week that elapsed after starting the cultures before Milorganite extract was supplied, during which time the cultures were, of course, lacking in the minor nutrient elements. Since Milorganite extract did not stimulate additional growth in control cultures which already contained all of the minor nutrient elements, it is evident that the highly stimulating effects of the extract, which were observed in the other cultures, can be attributed only to the presence of available minor nutrient elements in Milorganite.

These observations and results undoubtedly explain, at least in part, the additional unusual stimulating effects which have been noted following the use of Milorganite on certain soils.

SUMMARY

The availabilities of the minor nutrient elements in "Milorganite" and their influence on plant growth were studied by growing corn, tomatoes, and sunflowers in nutrient solutions, some of which were supplied with carbonated water extract of Milorganite as the only source of boron, copper, manganese, molybdenum, and zinc. The tomato and sunflower plants were analyzed for each of these elements, except molybdenum, and corn for each except boron and molybdenum. The results obtained may be summarized as follows:

Corn made very little growth and exhibited typical deficiency symptoms in solution cultures from which either manganese or zinc was omitted, while a fairly large but abnormal growth resulted where copper was omitted. The addition of Milorganite extract to some of these cultures during the last 2 weeks of the 7-week growth period resulted in the resumption of normal growth in each instance. Milorganite extract increased the yield in all cases except in controls which were already supplied with all nutrients. Increases in the amounts of copper, manganese, and zinc absorbed by the plants were noticed wherever the extract was supplied.

Tomato and sunflower plants made good growth in every culture where Milorganite extract served as the only source of one or more of the minor elements. Inferior growth, exhibiting deficiency symptoms, was generally observed in the series of duplicate cultures which did not receive the extract or other sources of these elements. In all cultures that received it, except controls, Milorganite extract significantly increased the dry weights of the plants and the contents of boron, copper, manganese, and zinc.

The results of the investigation show clearly that Milorganite when used as a fertilizer or as a constituent of mixed fertilizer may serve as a source of the minor nutrient elements for plant growth.

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NOTE

A CONTAINER FOR GROWING PLANTS FOR ROOT STUDIES

THE container described here and illustrated in Fig. 1 was designed to obtain data on the relative depth to which certain grasses would root under similar conditions. Since it served this purpose very satisfactorily, a brief description is submitted for the use of others who may be interested in similar studies.

The can was made from 22 gauge galvanized iron unpainted. The upright portion of the container merely rests in the detachable bottom which is pierced to provide drainage. The upright portion is bent into shape and the detachable side is slipped inside the two flanges provided. The pressure of the soil within the container holds the fourth side in place after the can is filled. Metal screws are necessary to keep the container from spreading under the pressure developed by tamping, but need be set no closer than 6 inches. The detachable bottom holds the lower portion of the upright part, so no screws need be set in it.

The cans may be filled, set in the ground, and the crop grown for any designated period.

FIG. 1.—General view of the containers.

At the close of the growth period the cans may be dug loose, slipped up a plank, and laid on a plank or floor with the removable side up. The side may then be removed, as illustrated in Fig. 2. These operations expose the soil and the development of the roots may be observed easily, particularly at the bottom of the can, if the roots penetrate so deeply. The soil may then be marked off at definite intervals and various layers sliced off and the roots washed out. The fact that the side may be removed makes it possible to detach these layers quickly and accurately.

The containers illustrated were made 10×10 inches and 4 feet deep. They were small enough to be handled fairly easily and deep enough for this study. There was no indication of buckling, however, and the cans could be made larger if desired.

Each screw should be greased as it is set and a little grease applied to the inside of the detachable bottoms to make sure that they will

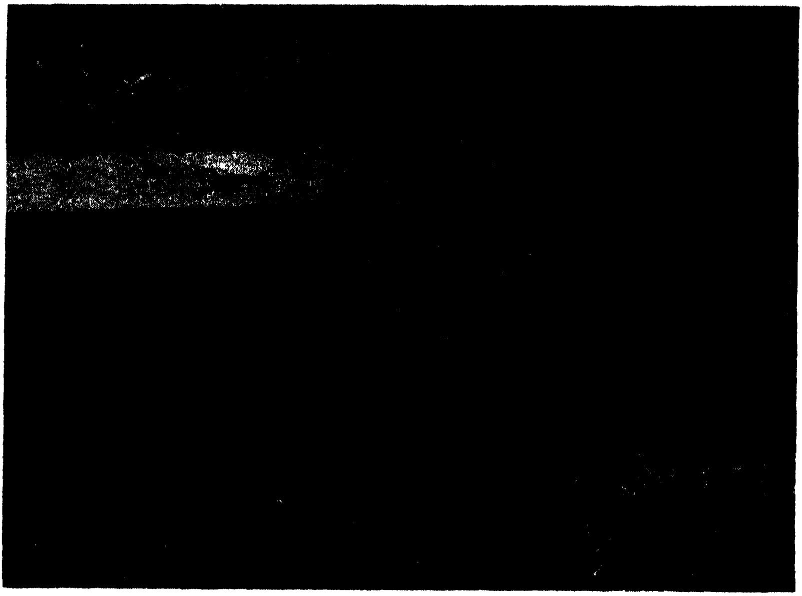

FIG. 2.—Side removed from container with soil exposed.

come apart easily at the close of the growing season. They may be used for several tests.—NEWTON L. PARTRIDGE, *Department of Horticulture, Michigan State College, East Lansing, Mich.*

BOOK REVIEW

GENERAL BACTERIOLOGY

By D. B. Swingle. New York; D. VanNostrand Co., Inc. XII+313 pages, illus. 1940. $3.

THIS book is intended for beginners in bacteriology and it is very elementary. It differs in two respects from many recent text books in this field: The bacteriological aspects of the subject are treated rather less prominently than the more fundamental principles of bacteriology as a science; comparatively little attention is given to yeasts and molds, because of the fact that they are not bacteria and in the author's opinion should be treated separately.

Special interest from the standpoint of agronomy is the fact that 23 pages are given up to the matter of bacteria in soil. This amount of space compares very favorably with the 46 pages given up to pathogenic bacteria. (H. J. C.)

AGRONOMIC AFFAIRS

PROFESSIONAL WORKERS WANT COMPRESSED COURSES

THE May issue of the JOURNAL carried a news note with regard to special short courses for professional workers to be made available at the Agricultural and Mechanical College of Texas during the summer of 1940. The interest which was taken in these courses and the indications that were received as to the value of such courses to the professional workers of the country makes it worthwhile to report the outcome of this summer's trial.

Three outstanding conslusions were reached, as follows: First, professional workers want compressed courses which can frequently be accomplished during short or vacation periods. Second, outstanding visiting instructors can frequently be obtained for such short periods. Third, this type of graduate course permits keeping college instruction geared closely to the latest developments in action programs.

There was a total of 98 students enrolled in these special courses, approximately three-fourths of whom were established professional workers coming back for either a refresher course, a service course, or additional work towards their definite graduate program. These men came from a very wide geographical region and from many professional services. College and experiment station workers, vocational agriculture teachers, soil conservation workers, and employees of the extension service and the U. S. Bureau of Agricultural Economics were represented. The character of students thus assembled created a most helpful atmosphere and made it possible to bring into the class discussions an extremely varied amount of experience and background.

After contacting the instructors who handled these courses, it became rather obvious that even very busy and very prominent men in the educational and administrative fields were occassionally seriously interested in an opportunity to go to some other part of the country and teach some special course which fell within their specialty. Some of them remarked that it was extremely helpful to them to get away from the routine demands of their regular employment, which was frequently administrative, and be able to settle down with a group of stimulating students for three weeks of concentrated effort in collecting, re-organizing, and presenting the subject matter which they have in their minds and in their files but do not have sufficient time to organize under other conditions.

Perhaps of greatest significance was the opportunity such courses presented for bringing into our graduate instruction the very latest information and experience obtained through the operation of the action agencies. The necessity for doing this in connection with those types of agronomic work which these agencies have been developing on a previously unheard of scale has been very clear.

Most agronomists will appreciate the fact that much extremely valuable material is not available for general use because it has not had time to become crystallized in text-book and reference form.

Therefore, it is available to only a very limited number of people who happen to have had personal contact with these later developments.

In all of the special courses offered by the Department of Agronomy of the Agricultural and Mechanical College of Texas this past summer, it was obvious that the bringing together of outstanding authorities and teachers, some of whom were associated with action programs, and a distinguished and varied group of students, many of whom were busily engaged in exploring new fields of agricultural planning and development, gave a good setting for an inter-change of ideas which would bring the very latest and best plans clearly before the group for their consideration and information. It was felt that in view of the very rapid changes and advances being made in all types of agricultural science there was a practically unlimited field for bringing opportunities of this sort before professional workers of the country in order that all might keep as nearly abreast of developments as possible.

The courses offered this past summer included: forest soils, taught by Dr. R. F. Chandler, Jr., Pack Assistant Professor of Forest Soils, Cornell University, with an enrollment of 19 students; range management and ecology, taught by Dr. W. G. McGinnies, Chief, Range Research, U. S. Dept. of Agriculture, Southwestern Forest and Range Experiment Station, Tuscon, Arizona, with an enrollment of 16 students; the fundamentals of grass and pasture improvement, taught by Dr. F. D. Keim, Chairman of the Department of Agronomy, University of Nebraska, Lincoln, Nebraska, with an enrollment of 23 students; and soil classification and mapping, taught by E. A. Norton, Chief, Physical Surveys Division, Soil Conservation Service, Washington, D. C., with an enrollment of 40 students.

Throughout the summer the enrollment and interest increased as people learned more about the courses, and therefore it is hoped that other courses of this character may be made available in Texas in succeeding summers.—IDE P. TROTTER, *Head, Department of Agronomy, Agricultural and Mechanical College of Texas, College Station, Texas.*

MEETING OF CORN BELT SECTION

THE Corn Belt Section of the American Society of Agronomy held its annual field meeting at the Iowa State College at Ames on September 9 and 10. The experimental work in progress at the Agronomy Farm of the Iowa Agricultural Experiment Station was demonstrated and tours arranged to visit the southern Iowa Pasture Improvement Farm at Albia and to examine profiles of some of the major soil types.

The meetings were attended by 300 agronomists from 16 states and were followed on September 11 by a Regional Grassland Conference sponsored by the Society in cooperation with the Association of North Central Experiment Station Directors. Among the main speakers were Dean M. F. Miller, Dean H. P. Rusk, Dr. P. V. Cardon, Dr. O. S. Aamodt, and Extension Director W. H. Brokaw of Nebraska. The attendance was about 250.

USE OF POTASSIC FERTILIZERS IN GREAT BRITAIN

TO ensure that the available supplies of potash be used to the best immediate advantage, regulations have been drawn up by the Ministry of Agriculture in Great Britain, limiting the uses of such fertilizers to the following crops: First, for potatoes and truck garden crops (other than fruit); second for sugar beets and flax; and third for other crops only on those soils markedly deficient in potash.

Where barnyard manure is available or where potash has previously been applied in the rotation, further dressings, even for the above crops, must be omitted or reduced. The manufacturer of compound fertilizers low in potash is suspended. Vendors will be required to obtain an assurance from farmers at the time of sale that the fertilizers will be used in accordance with the directions.

WAR AND AGRICULTURAL ADJUSTMENT

LAST-minute arrangements have been made for a joint conference of the Crops Section of the American Society of Agronomy and of the Soil Science Society on the theme of war and agricultural adjustment, with special reference to grassland agriculture. Dr. O. S. Aamodt, chairman of the pasture committee of the American Society of Agronomy, will act as chairman of the conference.

The following program has been arranged for Friday afternoon, December 6, at the Drake Hotel in Chicago:

1. War and Our Changing Agriculture. Eric Englund, Bureau of Agricultural Economics.
2. Farm Adjustments to Meet Changing Conditions. Sherman Johnson, Bureau of Agricultural Economics.
3. The Relationship of Industry to Agriculture with Special Reference to the Defense Program. Louis H. Bean, Bureau of Agricultural Economics.
4. Panel Discussion—Agronomic Implications. Charles E. Kellogg, Bureau of Plant Industry.

NEWS ITEMS

DR. STEPHEN KLIMAN, formerly Director of the Wisconsin W.P.A. state-wide-county soil testing project, with headquarters at the College of Agriculture, is now chief soil chemist for the Standard Fruit and Steamship Company of Haiti with headquarters at Port-au-Prince. He will work principally with problems relating to banana culture. DR. DAVIS M. BATSON, who received his Ph.D. degree in soils at the University of Wisconsin last June, has also been employed by the same firm as first assistant to Dr. Kliman.

HARRY P. OGDEN, Associate Agronomist at the Tennessee Agricultural Experiment Station, died recently.

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A NUTRIENT ELEMENT SLIGHTED IN AGRICULTURAL RESEARCH[1]

FREDERICK J. ALWAY[2]

FOR more than a century sulfur has been recognized as an indispensable plant nutrient and for still longer sulfur fertilizers have been used extensively both in this country and Western Europe, but until very recently it has been thought unnecessary to apply sulfur as a fertilizer. The history of the use of sulfur fertilizers may be divided into *three* periods, calling the first the Reign of Gypsum, the second the Reign of Superphosphate, and the third, in which we meet, the Renaissance, or Modern Period. In the first, covering 80 or 90 years, from about 1760 to 1845, gypsum was used widely and its beneficial effects generally overestimated. In the second period, extending into the early part of this century, some 60 years in all, the need of any sulfur additions to the soil was ignored and the use of gypsum discouraged by agricultural scientists. The Modern Period dawned when a Russian chemist, Bogdanov, questioned the assumption that the natural supply of sulfur is everywhere sufficient for crops and three English agronomists, stationed at a county laboratory, put the question to a practical test on local fields. Following the work of these pioneers various localities have been identified in which sulfur-deficiency is common, or at least occasionally appears, but the crops now recognized as the first to show a need of sulfur fertilizer are practically the same as those known in the first period to be most benefited by gypsum.

THE FIRST PERIOD—EARLY USE OF GYPSUM

The earliest part of this period is best described by Pierre, who was professor of general chemistry and agricultural chemistry at the old French university of Caen. In his *Chimie Agricole*, which carries no date of publication, he reports his free public lectures given from 1848 to 1852, devoting some 30 pages to gypsum, other sulfates, and sulfuric acid. I shall quote a few paragraphs:

[1]Address of the President delivered before the thirty-third annual meeting of the Society at Chicago, Ill., December 5, 1940. Paper No. 1864 Scientific Journal Series, Minnesota Agricultural Experiment Station.

[2]Chief of the Division of Soils, University of Minnesota, St. Paul, Minn.

"The use of gypsum appears to have been known since time immemorial in Hanover. However, this use of gypsum began to spread only after the experiments of Pastor Mayer of Kupferzel in (the Swiss canton) Aargau.

"Mayer communicated the results of his experiments to the Economic Society of Bern; these appeared so extraordinary that they had them repeated in the following year before two special commissioners. On the 28th of February, 1768, gypsum was spread on part of a field of clover sown with wheat the preceding spring *on a healthy soil, neither clayey, nor gravelly, nor wet.*

"On May 7 the plastered clover, by its dark green color, distinguished itself in an astounding manner from that which surrounded it.

"Finally, cut on June 17, it was 104 cm. high and very vigorous. That which had not been plastered was (only) 35 to 50 cm. in height and had a yellowish color. Other trials made on a clover sown with oats the preceding year also gave good results.

"The following year (1769) the Commission made other trials on four parcels each of 4,000 square feet. The first received gypsum at the rate of 8 hectoliters per hektare, (about 9 bushels per acre), the second received quicklime at the same rate, the third was given marl at 4 times that rate. . . .

"After this time the use of gypsum spread in a truly extraordinary manner. Introduced into Dauphiny in 1771 it very quickly spread into other parts of France, to England and to Germany. However, it is especially in the United States that the (land) plaster has come into such common use that each year an immense quantity is imported, coming in large part from the quarries of Montmarte, near Paris.

"This introduction of gypsum to the United States dates from a memorable experiment made by B. Franklin. In spreading the plaster on a field of alfalfa situated beside a main road, near Washington, he traced the forever celebrated words: *This has been plastered.* The effect produced on the meadow was such that these words could be easily read by travellers passing on the road."

At the beginning of the nineteenth century according to Graham (1938) the annual import of gypsum into the United States averaged about 30,000 tons but soon climbed to 100,000 tons.

Rothamsted is often credited with the beginning of accurate experimental work with fertilizers, but the second director of that experiment station, Sir Daniel Hall, in his book "Fertilizers and Manures", states that the first man to undertake field experiments on a practical scale was Boussingault, farming his own land in Alsace in 1834. The third and present director of that station, Sir John Russel, in his "Soil Conditions and Plant Growth", uses as frontispiece a picture of Boussingault with the legend "The Founder of Modern Agricultural Chemistry". It is Boussingault that may be given the most credit for bringing the first period to an end, proving, as he believed, that the beneficial action of gypsum is due to its lime content and not to its sulfur. In 1844 he published his treatise "Rural Economy in its Relation with Chemistry, Physics, and Meteorology" and in this devoted much space to gypsum. In the following year

appeared an English translation by George Law. From the latter I should like to read a few quotations.

". . . The partisans of gypsum were guilty of exaggeration. They spoke of the substance as an universal manure, capable of supplying the place of every other, as advantageous for every description of crop, as applicable to every variety of soil. Experience soon set bounds to such indiscriminate laudation; it was found that gypsum alone was inadequate to produce fertility that it always required the concurrence of organic manures, if the soil did not contain them of itself; that it only acted beneficially on a certain, and that a very small number of plants; lastly, that it was upon artificial meadows, constituted by clover, lucern, and sainfoin, that it produced its best effects; its action, on the contrary, being scarcely perceptible upon natural meadows, doubtful in connexion with hoed crops and null with the cereals. . . .

"In some places, the number and extent of which are by no means inconsiderable, no good effect whatever has attended the application of gypsum, although it has been administered in favourable conditions and in connexion with crops that elsewhere derive the highest amount of advantage from its use. . . .

"A particular inquiry into the subject was therefore held worthy of its attention by the French government, and a comprehensive report on all the information collected, was made by M. Bosc to the Royal Central Agricultural Society of France."

Boussingault next proceeds to examine critically the then current explanation of the beneficial action of gypsum, one by Davy, the other by Liebig, rejecting both. He writes: "I was, therefore, induced to undertake a series of experiments with a view to study, independently of all hypothetical idea, the action of gypsum upon certain hoed crops and cereals.

"These experiments were made upon patches of land of 440 square yards each. Every precaution was taken to render the experiments strictly comparable one with another."

These plot experiments carried out in 1841, 1842 and 1843, included clover, wheat, oats, rye, and mangolds. As to Liebig's theory that gypsum absorbs ammonia from the rain water and that it is this that benefits plants, he writes: "The action of gypsum, limited as it is to certain crops, will not allow us to admit that it produces its effect by fixing in the ground the carbonate of ammonia contained in rain-water; were it connected with any fixation of ammonia, it would be manifested generally, and not in particular instances only. Davy's theory therefore appears the more plausible, and requires discussion. Did the ashes of the clover grown in gypsed soils actually contain a larger proportion of sulphate of lime, as affirmed by the illustrious English chemist, the action of gypsum would be readily understood. The whole question, therefore, seems to turn upon the composition of the ashes.

"I have analyzed the ashes of clover grown at Bechelbronn, without and with the concurrence of gypsum . . . The ashes of the clover grown upon soil without gypsum contain 6.0 per cent of sulphate of lime; those of clover grown upon a soil with gypsum, 5.7 per cent . . .

"There appears to be no doubt, therefore, that the sulphur required by plants is supplied abundantly by the soil enriched with ordinary manure, as happens in the culture of the cereals, roots and tubers.

"In a word, it may be presumed that Paris-plaster acts usefully on artificial meadows by introducing lime into the soil. This is consistent both with the analysis of the ashes of the crops produced and of the soil."

THE SECOND PERIOD

The lack of interest in gypsum and its mode of action during the following half century and more, a period when agricultural research was developing rapidly in this country as well as in Western Europe, is not to be attributed solely to Boussingault's work. A year before the appearance of his book Lawes had begun the manufacture of superphosphate, which, while providing phosphorus in readily available form, at the same time furnished even more sulfur that was equally available. In practice wherever a fertilizer was used it became superphosphate, either alone or in combination, often with sulfate of ammonia and even sulfates of potash and magnesium. So, incidentally, there was a greatly increased use of sulfur in fertilizers. The concentrated commercial phosphates, double, treble or triple superphosphates, and the metaphosphates had not yet appeared. As all the crops that responded to gypsum, accordingly, did equally well or much better with superphosphate, this new, double-action product drove gypsum out of consideration. During this long period there appears to have been no suggestion that it might be its sulfur content that caused the beneficial action of gypsum, except by Pierre, who mentioned experiments in which sulfuric acid applied to limed soils affected plant growth like gypsum but he doubted if this would be true in the case of soils deprived of lime. Gradually the benefit of gypsum applications came to be attributed to an increase in the availability of the potash in the soil—a base exchange phenomenon.

It is evident that during this second period sulfur in fertilizers was more than merely slighted in agricultural research.

THE MODERN PERIOD

The introduction of this, the Renaissance, is not to be credited entirely to the work of any second Boussingault. Prof. S. M. Bogdanov, a Russian chemist, in 1899 pointed out a probable insufficiency of sulfur in the soil for certain crop plants, after finding more sulfur in these than had been obtained by the older methods—the analysis of the ash. The first confirming field experiments appear to be those of Dymond, Hughes, and Jupe, carried out in 1896 to 1901 in Essex County, England, and reported in 1905 in the first volume of the JOURNAL OF AGRICULTURAL SCIENCE. They compared ammonium sulfate with the chloride and gypsum with no sulfate, using in their field experiments red clover, peas, cabbages, rutabagas, oats, barley, and permanent pasture. The opening and concluding statements in their paper "The Influence of Sulphates as Manure upon the Yield and Feeding Value of Crops" show that the Renaissance was already definitely started:

"An agricultural problem to which little attention has been directed

is the relation of the supply of combined sulphuric acid in the soil to the growth of crops . . .

"There is not sufficient sulphuric acid in the soil or supplied by rain for heavy yielding crops rich in albuminoid, either for the production of greatest yield or the highest feeding value, and for such crops a sulphate should be included in the artificial manure. For cereal crops and for permanent pasture the soil and rain provide all the sulphuric acid necessary."

It fell to the lot of Hart and Peterson in Wisconsin in 1911 to put clearly before agronomists the need of revising their attitude toward the needs of sulfur by crop plants. Preparatory to a study of the relation of wool production to the supply of sulfur in feeds, they acquainted themselves with the work of Dymond, Hughes, and Jupe and the improved methods of determining the sulfur content of plant material that had been developed by a succession of chemists from Berthelot in 1888 to Barlow in 1904. Showing that the crops removed about as much sulfur as phosphorus, they pointed to the small amount in soils, the heavy loss in drainage, and the small amount added in rainwater, as follows:

"It appears that for permanent and increased production of farm crops such systems of fertilization must be inaugurated as will supply to the soil from time to time, in addition to the elements now recognized as necessary, a sufficient quantity of sulfur to meet the losses sustained by cropping and drainage. Such sources of sulfur are farm manures; the trade fertilizers, such as superphosphates, ammonium sulfate and sulfate of potassium; and the so-called soil stimulant, gypsum or calcium sulfate. No attention, so far as we are aware, has been directed to this problem in America."

Two years later Wheeler, in his "Manures and Fertilizers," recognized the changing conceptions, mentioning that sulfur is "one of the elements supposed to be seldom, if ever, so deficient in soils as to require that it be applied artificially," but in view of the facts then known, especially the work of Hart and Peterson, thought the need of sulfur might bear investigating. As to gypsum, he considered that its beneficial effect upon plant growth might in some cases be due to its supplying either lime or sulfur, but that "in general the explanation is more properly to be sought in an indirect manurial action by the virtue of the liberation of other plant food elements."

Shortly after the publication of the Wisconsin work, Powers, Reimer, and Tartar found that on extensive areas in Oregon elemental sulfur, or any fertilizer containing sulfur, causes remarkable increases in the yield of alfalfa and other legumes. Later sulfur-deficient areas have been reported from other states, including Washington, Idaho, California, and Minnesota as well as from the Canadian provinces of Alberta, Saskatchewan, and Ontario.

LOSSES AND GAINS OF SULFUR

The amount of sulfur removed in crops is about equal to that of phosphorus. The late Dr. J. G. Lipman estimated the annual removal of these two elements in crops for the 370 million acres of crop land reported in the 1930 census to average 2.8 pounds of sulfur and 3.8

pounds of phosphorus per acre, with an annual loss in drainage of 41.8 pounds of sulfur but none of phosphorus. The addition of phosphorus in fertilizers to the same 370 million acres he estimated at 3.5 pounds per acre and that of sulfur at 3.9 pounds, thus leaving a deficit, if erosion effects be ignored, of only 0.3 pound of phosphorus per acre compared with a net loss of 28.6 pounds of sulfur, 95 times as much. Averaging all available top soil analyses in the United States, he found for the surface soil (6⅔ inches) only two-thirds as much sulfur as phosphorus, while the annual net loss of the former appears to be 95 times as much. In computing the average net loss of sulfur he omitted the 14.6 million acres of irrigated crop land for which he estimated an annual addition from the irrigation water of 227 pounds per acre of sulfur.

The difference of 16 pounds per acre between the gross and net loss of sulfur is accounted for by 1.5 pounds in manure, crop residues, and seeds, 3.9 pounds in commercial fertilizers, and 10.6 pounds from the rainfall. This estimate of 10.6 pounds per acre per annum from the rain is, I fear, based upon data many of which are misleading, the reported values being too high.

SULFUR IN RAIN AND SNOW

Determinations of the amount of sulfur in the rainfall have been carried out for at least some 90 years. In 1825, Brandes at Salzzufellen in Germany found sulfates in the rain, and in 1851, Pierre computed the amount of sulfur received by the land annually at Caen, a few miles from the English Channel, as 5.8 pounds. In 1852, Angus Smith at Manchester, England, reported finding sulfates in all the rain he examined, the quantity increasing with approach to the town. As general inspector of alkali works for the British Government, Smith was not interested in the beneficial effects of the sulfur in the rain but in its possible harmful effect upon health and its damage to buildings. He found that inland the sulfate content increased as large towns were approached, rising very high in these because of the sulfur in the coal used. In the rain water he found it to vary from a minimum of 0.24 p.p.m. at an inland country place in Scotland to a maximum of 42 p.p.m. in Glasgow. His book "Air and Rain" (1872) appears to have been overlooked by American investigators.

Numerous computations have been reported of the amount of sulfur per acre brought down in the rain, these apparently beginning, except for the single determination by Pierre in 1851 mentioned above, with those from Rothamsted for 1881 to 1887. In this country the amounts have been reported from at least nine states, in some cases calculated from water collected for only a few months, in others for 10 years or more, the annual amounts varying from 232 pounds near a smelter in Tennessee to less than 5 pounds in northern Minnesota. For the 53 stations outside of Minnesota for which I have found data, only 15% are reported as having less than 10 pounds per acre, 22% between 10 and 25 pounds, 46% between 25 and 50 pounds, and 17% still more. I suspect that many of these are too high, but I cannot decide from the information furnished in the

reports just which to thus suspect and I have no intention of asking information from any of the experiment stations as to just how the rainwaters already reported upon were collected for analysis. I know how the collections have been made in Minnesota and I am certain that all the annual amounts I reported at the Chicago meeting three years ago are too high, the error being very high for Minneapolis, decreasing with distance and becoming slight near the headwaters of the Mississippi. Collections and analysis of the snow waters at five of the original Minnesota stations have been continued. The sources of error located lie not in the chemical analysis or in the storage of the samples in glass bottles while awaiting analysis, but in the manner of collection. The concentration of sulfur in the rain-water poured from a rain gage, or other collecting vessel, may at times be even twice as high as that in the rain that entered it only a few minutes before. Further, the amount of sulfur in the water in the gage or other collector, not simply its concentration, may steadily increase with continued exposure to the atmosphere.

DISTURBING EFFECT OF SULFUR DIOXIDE IN THE AIR

Sulfur dioxide is the disturbing agent. It attacks most metal surfaces, including those of zinc, iron, steel, copper, brass, bronze, and alloys of copper with nickel and aluminum, the severity of the attack being affected by humidity, light, and the presence of other chemical compounds. If the metal surface be not protected by a SO_2-resistant coating, sulfates will be formed and these carried down by the next rain will raise the sulfur content of the water submitted to analysis. So it becomes necessary to use collectors of material not subject to corrosion by SO_2, or to protect all metal surfaces with which the rain comes in contact by a coating of some paint or enamel which itself will not contribute sulfur. Water thus collected is satisfactory for analysis if transferred to a stoppered bottle promptly after the rain or snow stops falling; otherwise the SO_2 in the air, if present in sufficient amount, reacts with the water, forming sulfuric acid, the latter increasing with continued exposure. If the water be led from a properly protected collecting funnel directly to a glass bottle, or suitable stoneware jug, by a connection that reduces to a minimum the circulation of air within the bottle or jug, such constant attention becomes unnecessary and collections need be made no oftener than monthly. Rain gages are ordinarily constructed of brass, bronze, copper, or galvanized iron, all corrodible. Those of the U. S. Weather Bureau are designed to measure accurately the rain, not the sulfur in the rain.

Where an open collecting vessel is used, even if of non-corrodible material, and emptied only monthly or bi-weekly, the found amount of sulfur will be too high unless the sulfur dioxide content of the air is very low, the error increasing with the concentration of SO_2 and the rate of movement of the air over the water surface.

A CONVENIENT METHOD FOR MEASURING THE SO_2 IN THE AIR

As the SO_2 in the air has such a disturbing effect, it is desirable to have some convenient means of measuring its relative amount during

the successive periods of collection. This is provided by the so-called "lead peroxide" method devised by the Department of Scientific and Industrial Research of Great Britain to furnish a measure of the attack of sulfur compounds on building materials. Small cylinders, called "candles", carrying 100 sq. cm. of cotton fabric coated with lead peroxide paste, are exposed freely to the movement of the air while protected from the rain by a cowl or roof. At the end of the month, or more frequently if desired, the peroxide-coated fabric is changed and the amount of sulfate on it determined, correcting for whatever had been in the peroxide coating before exposure.

AMOUNT OF SO_2 IN MINNESOTA AIR

Such candles have been exposed in duplicate at the Minnesota stations for over four years. While the British reports give their data as milligrams of SO_3 per 100 sq. cm. of exposed surface, we express ours as pounds of sulfur per acre. The highest amount we have measured was found on the roof of the building housing the Minnesota section of the U. S. Weather Bureau, located in the heart of the business district of Minneapolis. The total for 12 months was 532 pounds per acre, with a maximum of 74 pounds in November and a minimum of 16 pounds in June. The other extreme is found in northern Minnesota where three stations show an annual absorption of only 3 to 5 pounds with no great difference between summer and winter months, but with every month giving a measurable amount of sulfate. At University Farm, at the edge of St. Paul, the exposures are made only from 300 to 500 yards from the 210-foot stack of a heating and power plant thru which is discharged annually the products of combustion of some 9,000 tons of coal carrying about 135 tons of sulfur. Here the absorption during the summer varies from 5 to 7 pounds a month and in the winter from 18 to 22 pounds, with an annual total of about 120 pounds. In England for the 5-year period ending with March 1938, the annual absorption per acre of exposed surface at Westminster Bridge in London was 591 pounds and at Rothamsted 70 pounds.

RELATION OF SULFUR IN THE RAIN TO SO_2 IN THE AIR

In general, the greater the concentration of SO_2 in the air the higher is the monthly fall of sulfur in the rain, but the relationship is not definite or simple. At Bemidji, where we have the longest record of our northern stations remote from the combustion of large amounts of coal, the annual absorption of sulfur for the past 4 years has been 3.6 pounds per acre and the amount brought down in rain a little higher, 4.5 pounds. At University Farm during the past 12 months, using all the precautions in collection I have suggested, the rain and snow have brought down 12.5 pounds per acre of sulfur while the peroxide surface has absorbed at the rate of 112 pounds, nine times as much. At Bemidji, with its low SO_2 concentration in the air, well-coated metal collectors have shown only a pound per acre less sulfur than the latest U. S. Weather Bureau gage of copper with brass divider and measuring tube. At the same station no significant difference in sulfur was found between two coated copper col-

lectors, one of which was emptied after every storm and the other only at the middle and end of the month. On the contrary, at University Farm, with its high content of SO_2 in the air, both the protection of the metal parts of the collecting vessel and the promptness of emptying water seriously affect the results. An unprotected gage gave twice as much sulfur as did one with all the exposed parts either of coated metal or of glass, both being emptied after every storm. The sulfur taken up by water left two weeks in an open cylinder of coated metal or stoneware has been found to exceed even that brought down in the rain during the same interval.

So far as concerns the reliability of published data on the addition of sulfur to the soil by the rain, I suggest that the high values be regarded with extreme suspicion, unless it can be established that the collecting vessel did not present a corrodible surface to the water and also that the rain or snow was transferred from the collecting vessel promptly after each rain or fall of snow. The lowest values, on the contrary, may be considered not far astray, even if these two precautions were not observed.

A RUSSIAN STUDY OF PRECIPITATION

The most important paper on the amount of sulfur in precipitation, in my opinion, is that by Kossowitsch which appeared in 1913 in the Russian JOURNAL OF EXPERIMENTAL AGRONOMY. He had collections of the precipitation made at eight stations in European Russia during 1909, 1910, and 1911; at one station for only 9 months, at another for 2½ years, and at the others for periods intermediate between these extremes. One station was at the Agricultural Institute in St. Petersburg and a second at the nearby Forestry Experiment Station, and at both the annual amount of sulfur found was 28 pounds per acre. At an observatory 19 miles south of the city only 6.1 pounds were found. At four stations remote from both cities and coal burning factories very low annual amounts were found, *viz.*, 3.8, 2.6, 3.2, and 2.7 pounds per acre, the respective distances of these stations from St. Petersburg, all to the south or southeast, being about 45, 350, 600, and 950 miles. At the Forestry Experiment Station near the industrial city of Mariupol, on the Sea of Azov, also about 950 miles southeast of St. Petersburg, the amount was 20 pounds per acre. There is no information as to the character of the collectors used. Collections of the water were made at least monthly. There appears no reason to suspect that the low values reported for the four remote stations are too low. The high values for the three stations near the cities may or may not be high.

CONCLUSION

If the annual fall of sulfur in rain and snow at stations in Russia remote from coal-burning towns is less than 4 pounds per acre and at stations in northern Minnesota is only 4 or 5 pounds, what may we find elsewhere *in the open country* in North America? The amount of sulfur in the soil is low and its loss in drainage is high over much of this country. Its chief replenishment is from the air, but as to the extent of this replenishment we have but little information.

THE USE OF TENSIOMETERS FOR FOLLOWING SOIL MOISTURE CONDITIONS UNDER CORN[1]

M. B. RUSSELL, F. E. DAVIS, AND R. A. BAIR[2]

SEVERAL workers (2, 3, 5)[3] have recently shown that tensiometers may be used successfully in studying certain soil moisture problems. The instruments have a particular advantage where it is desired to obtain a continuous record of soil moisture conditions at several depths without disturbing the soil after the original installations have been made. During the summers of 1938 and 1939 soil moisture conditions under growing corn (maize) were followed by the use of tensiometers in conjunction with other studies on the interrelations among meteorological environment, soil conditions, crop response, and yield of corn.[4]

THE EXPERIMENTAL FIELDS

The soils of the field in which the plots were located in 1938 varied considerably. The southwestern part of the area was located on Clarion loam, the central part on Webster loam, and the central and southeastern parts were mapped as Webster silt loam. The locations of the tensiometer installations with respect to the soil type are shown in Fig. 1. The elevations at each installation site with respect to the central installation are:

Central location O

West + 0.75 foot	East −1.74 feet
South − 1.31 feet	Southeast − 2.80 feet

The soils of the area on which the plots were located in 1939 also showed considerable variation. The texture graded from Clarion loam in the southwest corner of the field to Webster loam in the central section and to Webster silty clay loam in the eastern third of the area. The soil boundaries and tensiometer sites are shown in Fig. 1. The elevations at each installation site with respect to the elevation of the southwest installation are:

Southwest	0	Southeast	− 3.53 feet
West central	− 0.89 foot	East central	− 3.95 feet
Northwest	− 1.16 feet	Northeast	− 4.38 feet

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[3]Figures in parenthesis refer to "Literature Cited", p. 930.

[4]This study is a cooperative project between the Iowa Agricultural Experiment Station and the U. S. Department of Agriculture under Bankhead-Jones Special Research Funds and was conducted on the Agronomy Farm at Ames, Iowa. The authors wish to acknowledge aid given by Dr. L. A. Richards, under whose supervision the original installations were made.

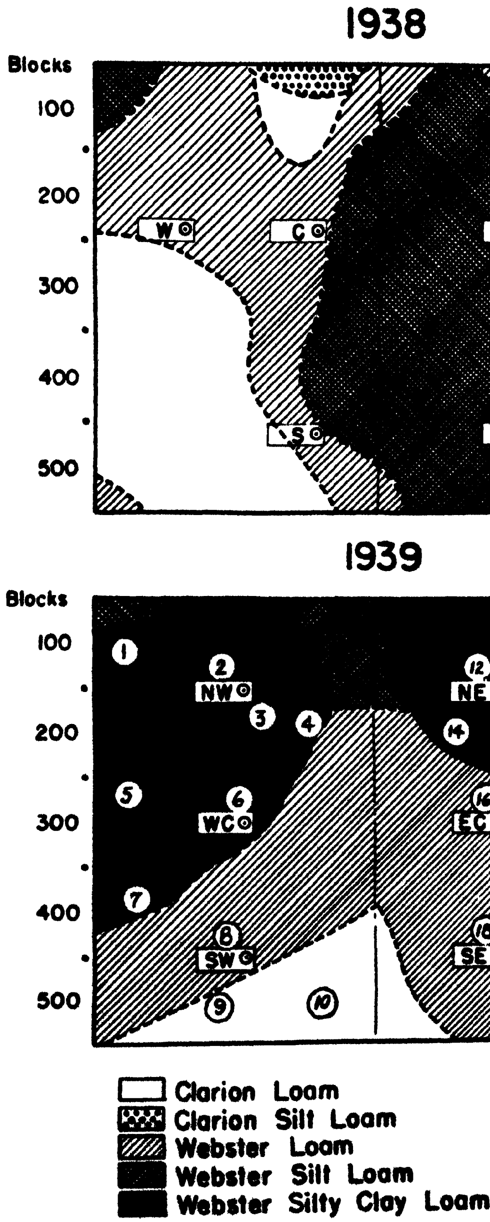

FIG 1.—Tensiometer locations and soil boundaries of the 1938 and 1939 fields.

The values for the permanent wilting percentage in Table 1 are the average of duplicate determinations made on each of the samples taken at the 6-, 18-, and 36-inch levels at each of 20 locations in the 1939 field. The location of the samples in the field are shown in Fig. 1. These permanent wilting percentage values tend to confirm the observed textural gradation in the surface soil of the area.

TABLE 1.—*The permanent wilting percentage of samples from three depths at each of 20 random locations.*

Location No.	6 inch depth	18 inch depth	36 inch depth	Location No.	6 inch depth	18 inch depth	36 inch depth
1	11.4	14.3	10.8	11	18.6	18.4	13.9
2	14.6	17.2	13.9	12	17.2	15.4	9.0
3	13.6	15.6	11.4	13	18.0	15.5	13.1
4	13.0	17.2	11.5	14	17.0	14.5	8.1
5	13.7	16.0	18.3	15	18.1	15.5	11.0
6	14.3	15.5	11.6	16	19.1	17.2	8.9
7	12.3	11.8	6.8	17	18.1	15.9	12.0
8	12.8	12.4	9.0	18	15.1	16.7	14.3
9	10.9	14.9	14.3	19	12.5	14.6	8.4
10	10.8	11.9	9.6	20	17.3	16.3	13.4

Volume weight determinations also were made at various depths in the area. The data are summarized in Table 2. These determinations were made from soil samples of known volume and were obtained by the use of a sampling tube having a $\frac{13}{16}$-inch bore. The samples were taken at random locations in the field at weekly intervals throughout the summer of 1939. A significant difference was observed in the volume weight of the surface 6 inches between the southwest and the northeast quarters of the field. The mean volume weight and standard error of the former was $1.391 \pm .035$ and of the latter $1.239 \pm .027$.

TABLE 2.—*Volume weight of soil from different depths.*

Sample depth, inches	Number of samples	Vol. weight, grams/cc
0–6	215	$1.308 \pm .014$
6–18	215	$1.315 \pm .0084$
18–30	203	$1.387 \pm .0079$
30–42	203	$1.555 \pm .0078$
42–54	79	$1.661 \pm .017$

THE TENSIOMETER INSTALLATIONS

The tensiometers were of the spout-top type that has been described elsewhere (1). The tensiometer manometers were mounted on individual wooden stakes driven in the ground about 2 feet from the installations. A special stainless steel scale was devised with which it was possible to read the tension directly in centimeters of mercury.[5] The scale was graduated in units of 1.08 cm, since it has

[5]These scales may be purchased from the College Instrument Shop, Iowa State College, Ames, Iowa.

been shown (2) that the height of the mercury column in a tensiometer manometer is 8% greater than the tension if the latter is to be expressed in centimeters of mercury. The tensiometers were installed at the desired depths with the aid of a soil auger having the same taper as the porous cups. The porous cup must make good contact

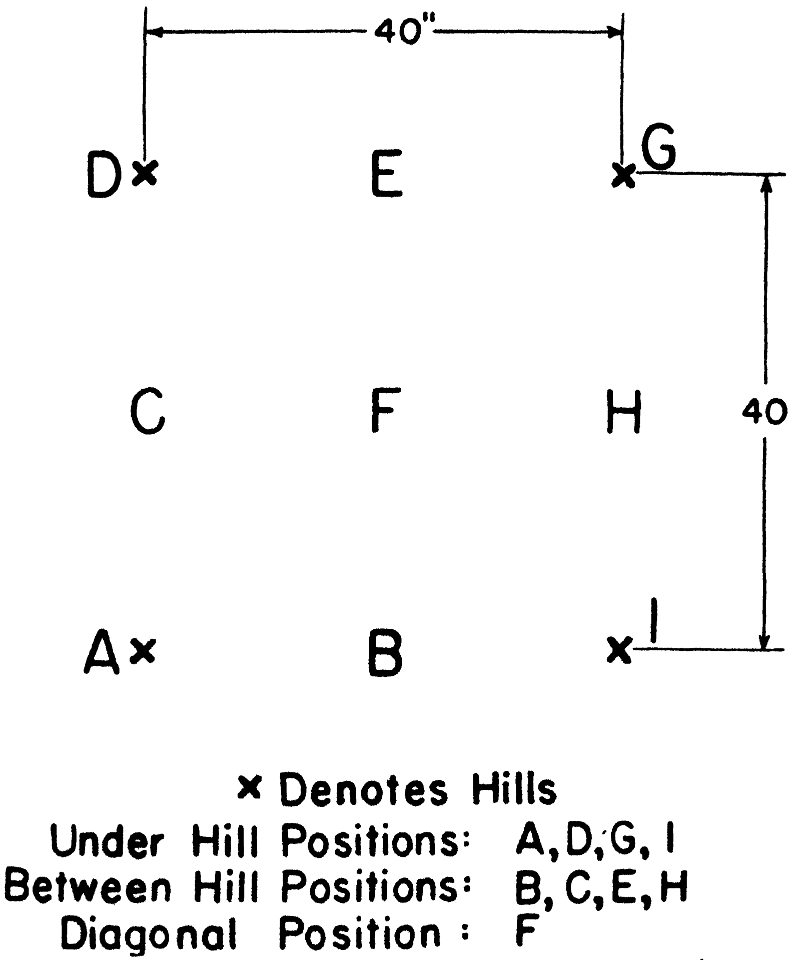

FIG. 2.—Positions of tensiometers with relation to hills of corn at the central location in the 1938 field.

with the soil, and therefore the auger holes were carefully made. After the tensiometers were placed in the auger holes, soil was tightly packed around the upper end of the tensiometer tubes to prevent water from following down the outside of the tubes to the porous cups. Some trouble was experienced with air leaks that developed at the connections between the rubber and copper tubing. Leaks of this kind were accompanied by a reaction between the copper and

rubber, probably the formation of copper sulfide. It is thought that this trouble may be eliminated by protecting the ends of the copper tubes by bakelite or chromium plate.

In the spring of 1938, tensiometers of the type described above were installed at five locations in the 2-acre test area as indicated in Fig. 1. At each location four tensiometers were installed at the depths of 12, 24, 36, and 60 inches at a position equidistant from four adjacent hills of corn, as position F in Fig. 2. This position will be hereafter referred to as the diagonal position. At the central location in the field, Fig. 1 C, additional tensiometers were installed at 6-, 12-, and 24-inch depths under each of the four adjacent corn hills and at positions midway between each pair of corn hills as shown in Fig. 2. Under two corn hills additional cups were installed at depths of 36 and 48 inches.

In 1939, installations were made at the 12-, 24-, 36-, 48-, and 60-inch depths at each of six locations in the test area as shown in Fig. 1. At each location the tensiometers were placed in the diagonal position, equidistant from four adjoining corn hills as in 1938.

EXPERIMENTAL RESULTS

The relation between the tension of the soil water and the moisture content of the soil has been studied previously for several soils and has been shown to depend on several factors, principal of which are texture and structure of the soil and the previous soil moisture conditions (4). As has been pointed out above, the soil in which the tensiometers were installed possesses considerable variation in texture at different depths as well as at different locations in the field. Consequently, a moisture sorption curve for each of the soil types represented would be required to interpret the tension readings in terms of soil moisture percentages. Although the soil variability largely precludes the possibility of an accurate conversion to moisture percentages in the field, it does not interfere with studies of moisture moving forces or moisture availability inasmuch as these phenomena are dependent primarily upon the tension of the soil water.

The data obtained from the 34 tensiometers installed at the central location in the 1938 field gave a rather complete picture of the moisture conditions beneath the four corn hills. The zones from which the corn roots progressively absorbed moisture during the summer of 1938 are indicated by the data summarized in Fig. 3. It will be seen that the tension readings began to increase rapidly first at the 6-inch level, then at the 12-inch level, 24-inch level, and 36-inch level at successively later dates. At each level the tensiometer beneath the corn hill was the first to show the effects of lowered soil moisture content, followed or accompanied by tensiometers at successively greater distance away from the corn plants. These data indicate that the zone of moisture absorption begins at a shallow depth directly beneath the corn plant, then spreads until a major portion of the available moisture at that depth has been used. Next, the zone of absorption extends to a greater depth where it once more expands from a point directly beneath the corn plants until finally the available moisture at this depth is also exhausted. In the area studied in

1938 the zone of extensive moisture depletion extended roughly to the 48-inch depth.

The above information on the zone of moisture absorption indicates that the placement of the tensiometers in relation to the corn plants is important. Where interest centers on the comparison of

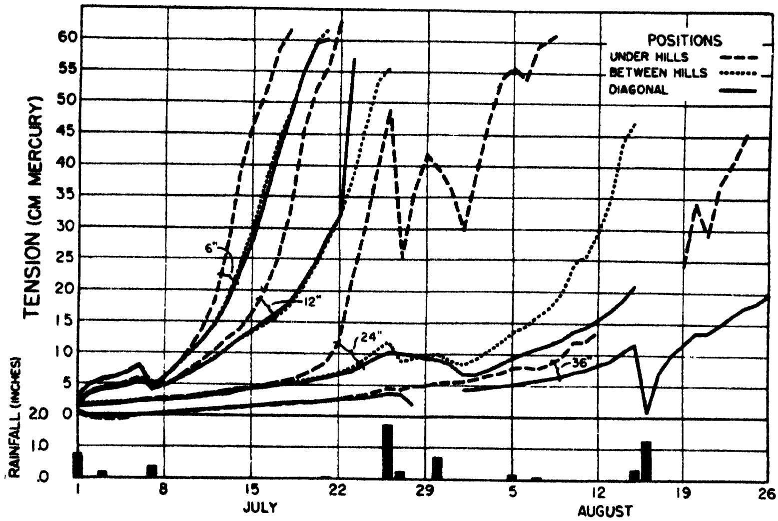

Fig. 3.—Tensions at four depths and three positions throughout the 1938 season at the central location.

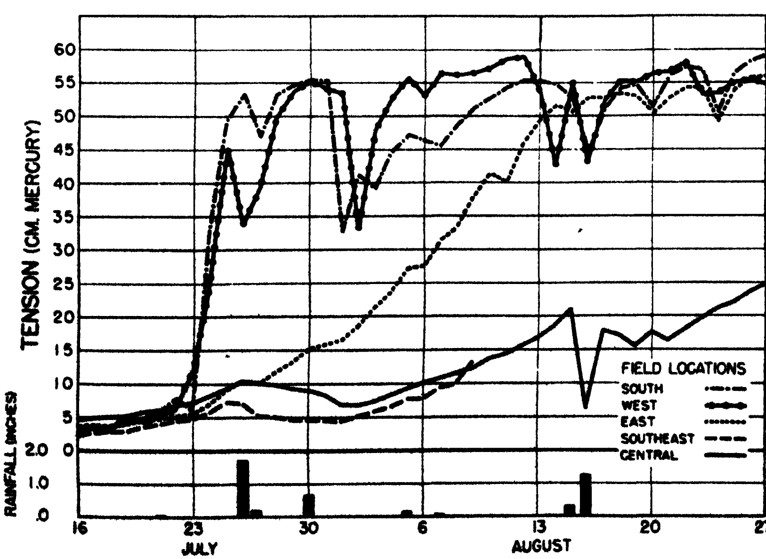

Fig. 4.—Tensions at the 24-inch depth at five field locations in 1938.

soil moisture conditions from year to year, as in the case of the project from which the present data are taken, the diagonal position of the tensiometers appears superior. The moisture at this position represents the last of the reserve at any given depth, and it is the depletion of such reserves that foreshadows critical moisture conditions for the plants.

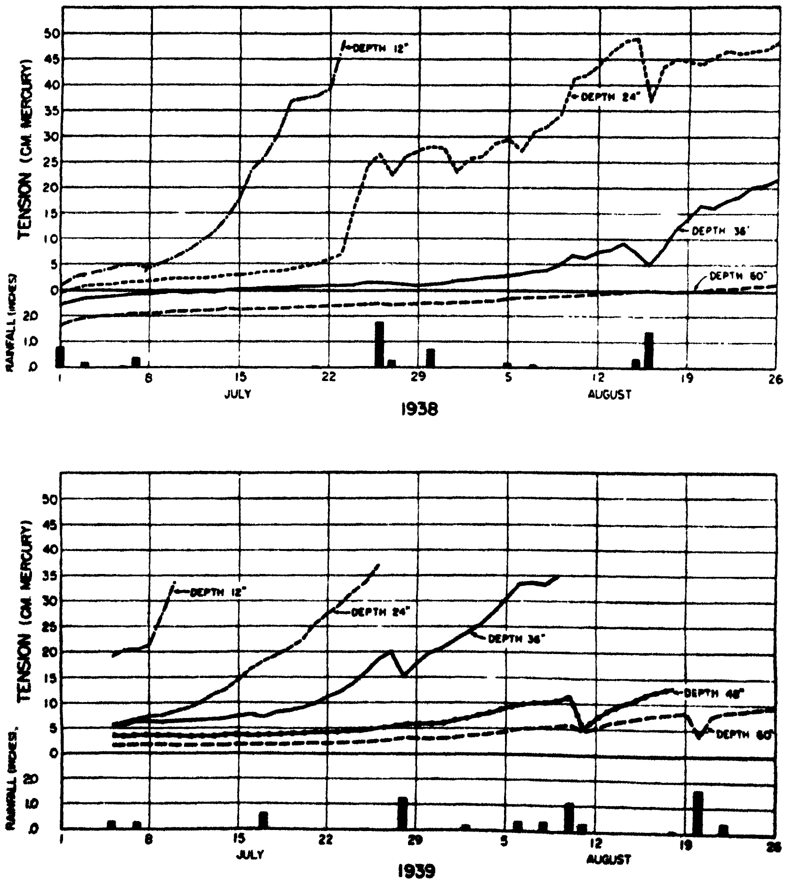

FIG. 5.—Tensions at various depths at the diagonal position for 1938 and 1939, average of all locations in the field.

Fig. 4 shows that wide differences occurred between the tensions recorded at corresponding depths at the several locations in the field. During the early part of the growing season the tension readings at all locations were in close agreement. As the transpiration load increased, however, the moisture content of the soil was decreased at each part of the field in a manner similar to that described above. Fig. 4 shows that the date at which the zone of extensive moisture

absorption reached the 24-inch level was quite different at the several tensiometer locations. The tensions at the south and west locations rose at an earlier date than did those of the other locations. This was due in part to the lower moisture storage capacity of the lighter textured surface soil in the southwestern part of the field. Other contributing factors may have been differences in crop growth, differences in elevation, and different transpiration conditions caused by unequal exposure to the prevailing winds. In 1939, similar differences were recorded between tensiometers installed at the several locations in the field.

Data from tensiometers installed in the diagonal position at each location in the fields are summarized in Fig. 5. The curves indicate that in both 1938 and 1939 the corn obtained its moisture from successively greater depths as the growing season progressed. It may be seen, however, that although the curves for 1938 and 1939 are of the same type, comparable rapid tension rises occurred at much earlier dates in 1939 than in 1938. These differences may be attributed to the larger size of the corn plants at any given date in 1939 as compared with their size on the same date in 1938. In 1939 the corn was planted on May 8, whereas in 1938 it was planted on May 24.

Fig. 5 also reveals differences in the depth of the free water table in 1938 and 1939. Negative tension values indicate that the tensiometer cup is below the free water table and consequently is subjected to a pressure greater than atmospheric. Fig. 5 shows that the free water table was about the 60-inch depth until August 15 in 1938, whereas in 1939 the water table was below the 60-inch depth during the entire period of measurement. Under conditions where soil moisture is at static equilibrium under gravity, the distance from a tensiometer cup to the free water surface may be calculated from the manometer reading. Such a calculation indicates that on August 15, 1939, the water table was 97 inches below the soil surface as compared to a depth of 60 inches at the same date in 1938.

CONCLUSIONS

1. Tensiometers installed at depths ranging to 60 inches at several locations in 2-acre fields successfully followed soil moisture conditions under corn during the 1938 and 1939 growing seasons.

2. Corn roots first absorbed moisture at a shallow depth directly beneath the corn hills. The zone of absorption extended laterally until most of the available moisture at that depth was depleted. The lateral expansion of the moisture absorption zone occurred at successively lower depths as the growing season progressed.

3. Because of the character of the zone of moisture depletion, the position of the tensiometers with respect to the corn hills influenced the type of information secured. Data from the cups installed equidistant between four adjacent corn hills were the most reliable for making year to year comparisons of soil moisture conditions.

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THE EFFECT OF SELECTION AND INBREEDING ON THE GROWTH OF BIG BLUESTEM (*ANDROPOGON FURCATUS*, MUHL.)[1]

ALVIN G. LAW AND KLING L. ANDERSON[2]

ANDROPOGON furcatus, commonly called big bluestem or bluejoint turkey foot, is one of the most valuable native perennial forage species in the tall grass or prairie region of the United States. It is found throughout the temperate region of North America (12)[3], although it is most important in the Flint Hills or bluestem pasture section of eastern Kansas and Oklahoma where, together with *A. scoparius*, it constitutes more than half of the total vegetative cover.

During the past two decades there has been a continued decline in the carrying capacity of the native grass pastures as a result of over-utilization. This condition, accentuated by the low rainfall of recent years, has focused attention on the native grass species from the standpoint of obtaining superior strains for restoring depleted pastures. In the development of such strains it is essential that the plant breeder possesses a knowledge of the variability and inheritance of the characters with which he must work. To this end studies of *A. furcatus* were initiated in 1935 by the Department of Agronomy of the Kansas Agricultural Experiment Station.

REVIEW OF LITERATURE

Various authors (1, 4, 8, 22) have adequately discussed the importance of *Andropogon furcatus* from the standpoint of forage production, palatability, and erosion control. It is an extremely variable species, exhibiting definite habitat groups that are distinctly different. Turesson (21) has drawn attention to the fact that species in nature contain certain groups which, primarily by reason of the selective influence of their environment, express a phenotypic constitution suited to the conditions of life in their particular habitats.

Gregor and Sansome (9) agreed with Turesson that there may exist in species definite habitat types and concluded that, although phenotypic uniformity was frequently attained by these wild populations, they were quite variable genetically and under the more severe eliminating influence of artificial selection such habitat types could again be separated into different growth habit groups.

Anderson and Aldous (2), working with *Andropogon scoparius*, found considerable genotypic variation within ecotypes but much greater variation between ecotypes.

In his work with *Lolium perenne*, Jenkin (13) concluded that, while individual plants from a fairly stable habitat might differ from one another phenotypically, the genotypic variation would usually be much greater. He found that plants from different habitats conformed to distinct general growth types.

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[2]Formerly Graduate Research Assistant and Assistant Professor of Pasture Improvement, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 943.

A partial explanation of the extensive variability exhibited by *Andropogon furcatus* may be found in the fact that the species is highly cross-pollinated (3), and consequently exhibits a variety of types. Furthermore, its chromosome number may vary. Church (6) reported the somatic chromosome number as 70, while Nielsen (17) found a type having 60 somatic chromosomes. Church (7) later found tetraploid and hexaploid forms of this prairie species having 40 and 60 chromosomes, respectively, and noted the relationship between polyploidy and the wide transcontinental range of *A. furcatus*. He reported diploid species of American *Andropogon* as occuring only along the Atlantic coastal plain in contrast to the wide range of the higher polyploid species and concluded that the greater stability of temperature and soil moisture of the coastal plain has contributed to this restriction of the diploids.

Inbreeding results in a depressive effect on the vigor of many cross-pollinated species. Significant reductions in plant height, winter hardiness, and seed production were reported by Nilsson (18) for *Festuca pratensis*, Huds., *Dactylis glomerata* L., and *Phleum pratense* L.

Stapledon (20) observed a loss of 50% in vegetative vigor of *Dactylis glomerata* following inbreeding which closely agrees with the work of Calder (5) on this species.

Jenkin (13) found a 63% loss of vigor as a result of inbreeding *Lolium perenne*.

Various workers (10, 11, 16) have reported much variation in the response of *Phleum pratense* to inbreeding, some lines being greatly reduced while others were as vigorous as the open-pollinated selections.

Williams (23) obtained a marked and a progressive loss in vigor as a result of inbreeding red clover but found some lines that were more vigorous than others. These, he found, were valuable for the production of improved strains by crossing since they tended to be strongly prepotent for high yield.

The effect of self-pollination on seed set of many grass species has been investigated by various workers. Anderson and Aldous (2) found that inbreeding reduced seed set of *Andropogon scoparius* 49 to 57%. Nilsson (18) obtained a range of 0–5% of normal seed set in inbred *Festuca pratensis* and a variation from complete self-sterility to self-fertility in *Dactylis glomerata* and *Phleum pratense*. Kirk (15) reported reduced seed set in selfed *Bromus inermis*, *Dactylis glomerata*, and *Lolium perenne*. Jenkin (14) encountered complete self-sterility in some *Lolium perenne* families and concluded that self-sterility was one of the greatest obstacles in the breeding of grasses.

MATERIAL AND METHODS

The breeding work on *Andropogon furcatus* was started in 1935 at the Kansas Agricultural Experiment Station at Manhattan when the first generation, consisting of 200 individual plants, was set out for detailed observation. The seed for this nursery was obtained under conditions of open pollination from small, adjacent observation plots which were, in turn, grown from seed of particularly promising plants, most of which were found growing in a droughty location along an old railroad grade near Manhattan.

Five generations of selection in open-pollinated material in its first year of growth have been included in this study with additional observations on the second year growth of the first four generations. The second generation consisted of progeny from each of the original 200 plants. The third, fourth, and fifth generations consisted of progeny from selected plants of each preceding generation. In 1938, selections were made from the 1937 nursery plants in their second year of

growth to be compared with the selections made from the same plants in their first season of growth. Each generation of seedlings was started in the greenhouse in February and transplanted to the field nursery in May. The plants were all spaced 30 inches each way to reduce competition among them and to permit cultivation for weed control. Such an arrangement made possible the detailed observation of individual plants and permitted furrow irrigation during the drier part of the summer.

Detailed field notes were taken each year during the growing season and the maternal parents selected on the basis of these observations. Since 1937 a number of heads on several of the most promising plants have been bagged in parchment sleeves to study the effect of inbreeding, the inbred progeny to be compared to their open-pollinated sibs. These heads were allowed to mature within the bags and were harvested in October at the time the open-pollinated seed was collected.

During the fall and winter caryopsis counts were made on representative samples from each of the plants to determine the percentage seed set. Germination tests were made by planting the seed in moist soil in the greenhouse and covering it with a quarter of an inch of clean sand. After germination counts were obtained the seedlings were spaced into flats, 2 inches apart, 100 seedlings to each flat, and later spaced out in the nursery.

EXPERIMENTAL RESULTS

GENERAL VARIABILITY

Andropogon furcatus exhibits a wide range of adaptation to many soil types and to a variety of climatic conditions. Strains from Nebraska, Kansas, and Oklahoma grown in the Manhattan nursery indicate there are definite ecotypes in this species which have developed as a result of natural selection over a long period of time. In general, the northern plants are earlier, smaller, and less leafy than those of southern origin, while the plants from Kansas are intermediate in these characters. The average heading date of the Nebraska plants was 21 days earlier than that of the Kansas plants, while the Oklahoma plants headed 47 days later than those from Kansas. Variations equally as great can be seen in leafiness, number of culms, and height. Fig. 1 shows the difference in growth habit of typical plants from these three strains.

Within ecotypes of *Andropogon furcatus* there are also definite natural variations in many characters. Although it is not as obvious as the variation between ecotypes, this variability can be perceived readily upon close observation of any one ecotype. It is this variation that has been utilized in the selection of superior lines from the Manhattan ecotype.

EFFECT OF SELECTION ON LEAFINESS

Leafiness is the most important single consideration in the selection of a superior plant of *Andropogon furcatus*. Total leaf area of the individual plants at their most leafy stage was calculated by multiplying average length of leaf by average width, by average number of leaves per culm, and by total number of culms in the manner described by Anderson and Aldous (2). This gave a value consider-

ably greater than the actual leaf area, but it was found to be satisfactory for purposes of comparison. The actual leaf area of each leaf as determined by planimeter measurements of 100 leaves selected at random was shown to be 68.1% of the calculated area.

The data relative to the effect of selection on the leaf area of *Andropogon furcatus* are presented in Table 1.

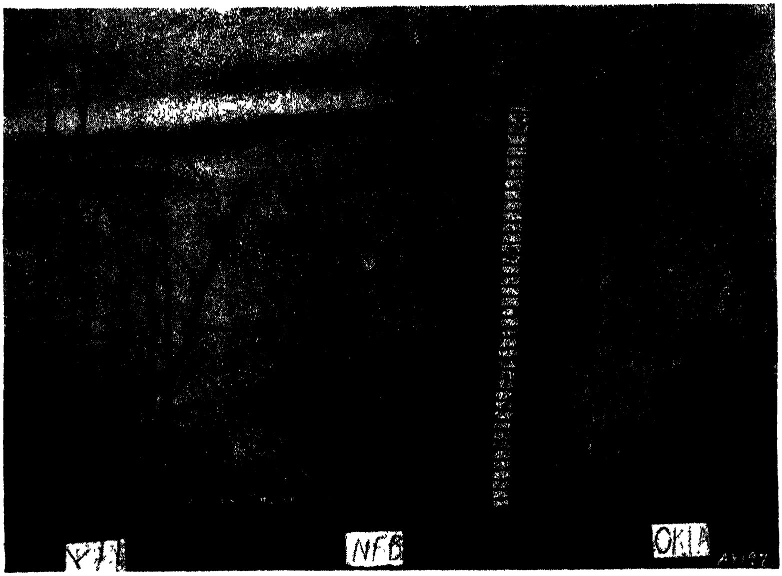

FIG. 1.—Variation in growth habit, leafiness, and time of maturity of *A. furcatus* plants grown in the Manhattan, Kansas, nursery from seed obtained in Kansas, Nebraska, and Oklahoma.

TABLE 1.—*The effect of continued selection on the leaf area of Andropogon furcatus*

Generation	Nursery	No. of plants	Mean and standard deviation (sq. cm.)	Coefficient of variation	Analysis of variance	
					F value*	1% level of significance
			First Season of Growth			
1st	1935	197	1296±910	70	—	—
3rd	1937	510	5237±2970	57	4.36	1.57
4th	1938	250	7497±3584	48	2.20	1.88
5th	1939	100	12986±6665	51	1.62	2.59
4th†	1939	120	10095±7407	73	3.89	2.40
			Second Season of Growth			
1st	1935	197	14160±9350	65	—	—
2nd	1936	190	26004±10309	40	3.07	2.31
3rd	1937	250	46703±20350	44	3.67	1.88
4th	1938	330	36697±12980	35	2.38	1.77

*Obtained by dividing variance between lines by variance within lines.
†Selection from second year growth, third generation (1937 nursery).

The highly significant F values of the early generations, obtained when comparing variation between progeny groups to that within progeny groups, would indicate there were distinct differences in the ability of the maternal parent plants to transmit the character leaf area to their progeny. It should be possible in such a population to bring about considerable improvement by continued selection of the desirable types from open-pollinated lines. The yearly means in Table 1 show highly significant increases in leaf area of the progeny groups in both their first and second seasons of growth following four generations of selection in open-pollinated lines. The slight advantage of the third generation over the fourth in the second season of growth is probably due to seasonal variation.

The general variability of the population has been decreased materially during the course of the experiment as is shown by the trend of the coefficients of variation in the successive selected generations. This is due, in a large measure, to the reduced variation between different progeny lines brought about by continued selection of similar individuals. It has been possible to eliminate a large percentage of the undesirable types leaving a population whose range of variability is narrowed somewhat. This conclusion is substantiated by the results of analyses of variance which show a distinct reduction in differences between lines compared to differences within lines.

From Table 1 it can be seen that there has been decidedly less total variation between plants in their second season of growth as compared to the same plants in their first season of growth. In analyzing data relative to the variability between individual plants exclusive of any variation between progeny groups, it was found that plants in their first season of growth gave an average coefficient of variation of 43% compared to 34% for the same plants in their second season of growth. Since the plants in their second season of growth exhibit less inter-plant variation, they should present more reliable material from which to make selections. To secure information relative to this point, selections were obtained from the third generation (1937 nursery) in both its first and second seasons of growth and the progeny from these two selections compared as to yield (Table 1). The data show a marked advantage for the selections from 2-year-old plants. This is especially important in view of the fact that the F values for the fifth generation selections indicate that there are no longer any significant differences between progeny groups of plants selected in their first season of growth. Selection in five successive generations toward a common type has resulted in the elimination of extreme types and has narrowed the range of variability in the population as a whole. Thus, the plants tend to be more like one another than is the case in unselected material. For this reason they must be grown long enough to permit full expression of their phenotypes before careful selections can be made, and the data indicate that further open-pollinated selection in such first-year material would be expected to yield little, if any, increase in leaf area. However, it would appear possible to extend the usefulness of selection in open-pollinated lines by careful choice of plants in their second year of growth.

EFFECT OF SELECTION ON NUMBER OF CULMS, BASAL DIAMETER, AND PLANT HEIGHT

Extensive data have been obtained relative to the effect of selection in open-pollinated lines on number of culms, basal diameter, and plant height. In each case it has completely substantiated the conclusions reached regarding the effect of selection on leafiness. For example, it has been possible to increase the mean number of culms per plant from 57 ± 29 to 148 ± 49 by four generations of selection. At the same time variability in this character, as measured by the coefficient of variation, has decreased from 51 to 33%.

In regard to plant height, it was felt that the extremely tall and extremely short plants were undesirable from a forage standpoint and consequently these types have been eliminated by the selection program. During the four generations of selection, average plant height at the most leafy stage of growth was reduced from 52 ± 8 to 30 ± 6 inches. Plants in their second season of growth were not significantly taller than they were in their first season of growth. Also, the variability in this character has been much lower throughout the experiment than that for leaf area and number of culms.

Basal diameter has been increased significantly by selection. However, because of the difficulty in obtaining accurate measurements and because of the extremely small differences between plants in this character, it has not been considered important in the selection program. Analysis of variance studies of number of culms, plant height, and basal diameter show that after the fifth generation of selection there were no longer any significant variations between progeny rows, whereas earlier generations had shown highly significant differences between lines. These facts emphasize the necessity of a more intensive method of breeding under conditions of controlled pollination if further improvement is to be accomplished.

EFFECTS OF INBREEDING

Inbreeding in *Andropogon frucatus* is accompanied by considerable loss of vigor in most of the inbred lines that were observed. In 1938, reductions in leaf area of 60 and 71% for the S_1 and S_2 generations, respectively, were obtained when inbred progeny were compared to their open-pollinated sibs. Similar figures were found for number of culms, maximum height, and basal diameter. In each character there is evidence that continued inbreeding is followed by a progressive decline in vigor. There is, however, considerable variation in the response of different lines to inbreeding, as is shown in Table 2. It is significant that the open-pollinated lines having the largest leaf areas have been reduced the most following inbreeding. Moreover, the inbred lines that have suffered little loss of vigor in S_1 have given progeny lines (S_2) that likewise are quite vigorous. This variation in response to inbreeding is shown in Figs. 2, 3, and 4.

A most obvious effect of inbreeding has been the segregation of the inbred sibs into rather distinct entities, making for greater variation between lines than is found in the open-pollinated sibs. For example, in the S_2 lines (1939 nursery) there is a highly significant

TABLE 2.—*Differences in size of various inbred progeny groups in comparison with their open-pollinated sibs (1938 nursery).*

Parent plant Nos.	Mean leaf area (average of 10 plants)			
	Open-pollinated		Inbred sibs	
	Mean and S. D.	Coefficient of variation	Mean and S. D.	Coefficient of variation
1	9244±3299	35	1118±810	72
2	8028±2422	30	2275±770	33
3	5287±2538	48	774±692	89
4	5939±1699	28	1041±514	50
5	5161±1917	37	1063±737	69
6	5160±2418	47	3185±937	29
7	6125±3307	54	3851±1687	43
8	4617±1741	37	2240±829	37
9	6193±1705	27	5019±5039	100+
10	5519±2585	46	5608±3938	70

F value of 7.37 (1% level of significance = 2.23) as compared to 1.62 (5% level of significance = 1.97) for the open-pollinated lines. Furthermore, there is considerable heterosis evidenced by the open-pollinated progeny of S_2 lines. These progeny show a mean leaf area of 13,794±6,721 sq. cm. compared to 2,192±1,696 sq. cm. for the maternal parents and 12,986±6,665 sq. cm. for the open-pollinated lines that have undergone five generations of selection for increased leaf area. Thus, it would appear that careful selection, inbreeding, and recombination of the inbred lines would be a logical method of strain building for *Andropogon furcatus*. These observations have been substantiated by data obtained on number of culms, basal diameter, and plant height which for the sake of brevity are not presented in this paper.

TIME OF MATURITY

Time of maturity, as measured by the appearance of the first five culms bearing inflorescences, has shown no significant change following four generations of selection of late-maturing maternal parents in open-pollinated lines. Sufficient data are not available to explain this failure to obtain late-maturing lines. It was observed that progeny rows from early-maturing parent plants have approximately the same average date of maturity and exhibit about the same range of variability as progeny from late-maturing plants. On an average, it requires nearly 35 days for a plant to complete the flowering process so there would be ample opportunity for pollen from the later flowers on an early plant to fertilize the earlier flowers on a late plant. The progeny from such a cross would vary for flowering date. There is some evidence that time of maturity is conditioned by length of day and temperature so that plants from a single ecotype would tend to head at about the same time, variations being caused by such factors as competition between plants, soil and moisture

variations, and various injuries resulting from transplanting and cultivation.

Inbreeding has affected the time of maturity of *Andropogon furcatus* only in so much as it has reduced the vigor of certain plants to the point that they were unable to produce heads. The inbred

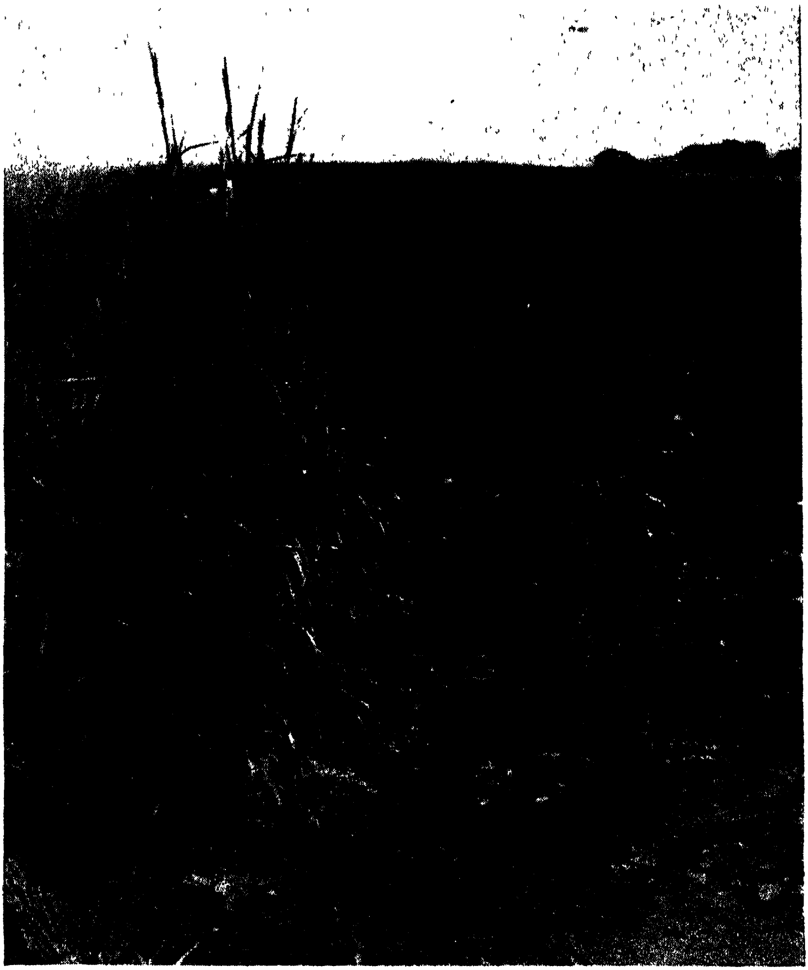

FIG. 2.—Extreme loss of vigor following two generations of inbreeding *A. furcatus* shown by the inbred row on the right in contrast to the open-pollinated sib on the left.

plants that were vigorous enough to flower did so at the same time as their open-pollinated sibs. About 45% of the inbred plants in the 1938 nursery failed to head at all in their first season of growth due, apparently, to the extremely weak condition of many of the plants. A similar percentage of the inbred plants in their first season of

growth failed to head in 1939. No such definite segregation between lines in time of maturity could be observed in the inbreds as was found for total leaf area, number of culms, basal diameter, and plant height.

SEED PRODUCTION AND GERMINATION

Extreme variability has been observed in the amount of seed set as measured by the percentages of caryopses per spikelet. Data regarding this character are shown in Table 3. In 1939, seed set in the

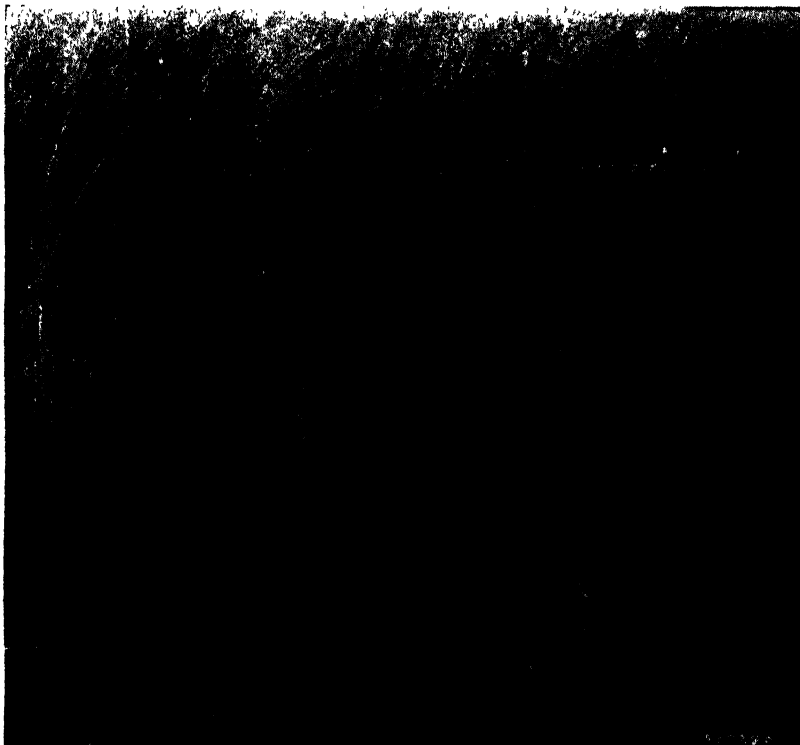

FIG. 3.—Moderate loss of vigor following two generations of inbreeding *A. furcatus* shown by the inbred row on the left in contrast to the open-pollinated sib on the right.

open-pollinated plants ranged from 0 to 84% of the spikelets filled. The later plants mature more seed, as a rule, since most of the heads that appear early in the season are blasted by the hot, dry winds of late July and August.

It was also evident that the most desirable plants from a forage standpoint are not the best seed producers. A line selected for high total yield, quality, leafiness, and uniformity gave an average seed set of 31±8.06% compared to 52±11.01% for a coarse, non-leafy strain.

TABLE 3.—*Percentage of spikelets filled in A. furcatus, 1937–39, inclusive.*

Treatment	Number of caryopses per 100 spikelets (av. of 300)				Average
	Open pollinated	Inbred, 1936*	Inbred, 1937	Inbred, 1936–37	
Seed Obtained in 1937					
Open-pollinated	45.9 ±20.70	50.59±21.07	—	—	48.25
Inbred........	7.03± 7.37	8.76±10.07	—	—	7.89
Seed Obtained in 1938					
Open-pollinated	17.56± 9.71	15.63± 9.33	13.30± 9.42	9.95± 8.65	14.11
Inbred........	1.11± 1.62	0.33± 0.61	1.93± 3.18	2.70± 3.32	1.51
Seed Obtained in 1939†					
Open-pollinated	37.40±14.52	37.30±13.56	25.10±17.82	20.10±15.07	30.20
Inbred........	7.40± 6.20	10.60± 9.20	4.50± 6.43	3.40± 3.18	6.47

*Heads enclosed in cheesecloth bags which were not pollen proof.
†Selections from plants in their second season of growth (1938 nursery).

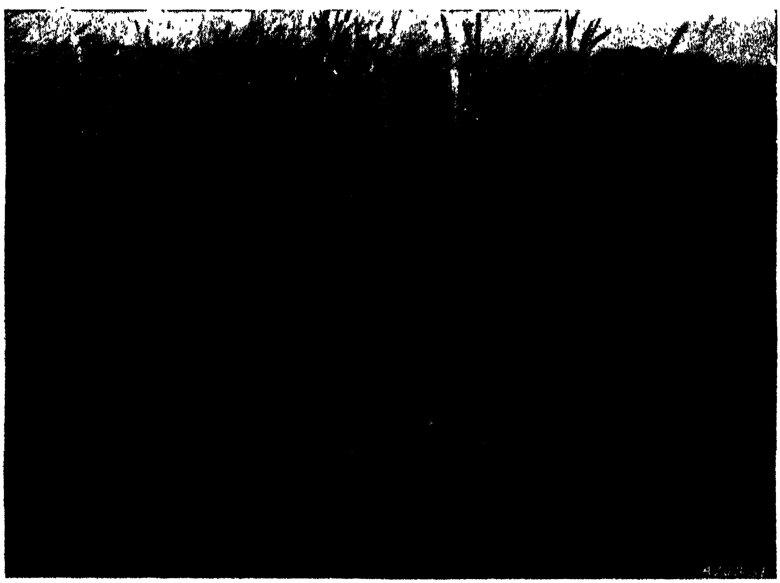

FIG. 4.—No loss of vigor following two generations of inbreding *A. furcatus.* Inbred row on the right, its open-pollinated sib on the left.

Inbreeding in *Andropogon furcatus* has resulted in reductions of as much as 84% in seed set under the selfing bags in the first inbred generation, while subsequent inbred generations have shown even greater reductions (Table 3). Whether this progressive decline in seed set is due to increased self-sterility following inbreeding or to the greatly reduced vigor of the inbreds, or to both factors, can not be determined from the available data. A range in seed set of the

inbreds from 0 to 42% would indicate that unfavorable conditions under the bag are of little importance in determining the percentage of seed set. Although self-sterility appears to be the rule, a few lines have been found that are highly self-fertile.

There have been no significant differences between germination percentages of the open-pollinated and inbred plants of *Andropogon furcatus*, nor has the time of seedling emergence varied significantly between the open-pollinated and inbred sibs. However, there has been considerable inter-plant variation in these characters that may be important from the standpoint of selection.

INTERRELATIONSHIPS OF CHARACTERS

Highly significant inter-annular correlations have been observed in each of the characters of leafiness, number of culms, basal diameter, plant height, and time of maturity, indicating that there are definite factors that interact with the environment to determine the expression of these characters.

A second group of correlations measuring the relationship between two variates is shown in Table 4. Various factors, such as the age of the plant, the effect of selection, and environmental conditions, may affect these values. It will be noted that leaf area and number of culms are most closely related, although leaf area and plant height show highly significant correlations in each of the years. Furthermore, there was no significant correlation between number of culms and plant height except in the unselected material. This would be expected since the number of culms was increased and plant height

TABLE 4.—*The correlation of various factors in A. furcatus.*

Nursery	Year of data	No. of culms	Maximum height	Time of maturity	Basal diameter
			Leaf Area		
1935	1935	———	0.288±0.065	———	———
1937	1937	0.766±0.028	0.405+0.049	0.304±0.005	———
1937	1938	0.778±0.018	0.352±0.040	0.236±0.024	———
1938	1938	0.662±0.036	0.307±0.037	−0.211±0.037	———
1938	1939	0.673±0.030	0.405±0.046	0.101±0.054*	———
1939	1939	0.695±0.052	0.257±0.093	−0.108±0.061*	———
			Plant Height		
1935	1935	0.496±0.054	———	———	———
1937	1938	0.017±0.033*	———	———	———
1938	1938	−0.036±0.055*	———	−0.279±0.049	———
1938	1939	0.113±0.017*	———	———	———
1939	1939	−0.117±0.099*	———	−0.167±0.057*	———
			Number of Culms		
1937	1938	———	———	———	0.331±0.041
1938	1938	———	———	———	0.486±0.048
1938	1939	———	———	———	0.408±0.040
1939	1939	———	———	———	0.478±0.069

*Not significant.

decreased by continued selection. Time of maturity shows no consistent relationship with leaf area, although early in the experiment the later plants were also the most leafy. Number of culms and basal diameter, as would be expected, were significantly correlated throughout the experiment.

SUMMARY AND CONCLUSIONS

Andropogon furcatus is one of the most important native forage species of the tall grass area of the United States. Investigation of the genetic behavior of this species with a view to the development of improved strains by open-pollinated selection was started in 1935 at the Kansas Experiment Station. The species was found to be extremely heterozygous in nature and to be divided into definite habitat groups or ecotypes which, in turn, were highly variable within themselves. This highly variable condition would be expected since the species is a polyploid of remote hybrid origin having a variable chromosome number and is highly cross-pollinated. The effects of selection and inbreeding on the variability and growth of a Manhattan, Kansas, ecotype are discussed.

That the variability of *Andropogon furcatus* is controlled by genic interaction with the environment is shown by the fact that highly significant variations have been found between progeny groups of different plants. Furthermore, by five generations of selection in open-pollinated lines of desirable plants as maternal parents, it has been possible to increase leaf area more than 22,000 sq. cm. for plants in their second season of growth and more than 12 times for plants in their first season of growth. At the same time, there has been a significant decrease in the variability of the population so that further improvement by selection in first season of growth material is not likely. The data indicate that it will be necessary to resort to selection in second and third year material to reach the ultimate degree of improvement by this method.

Extensive data obtained regarding number of culms, plant height, and basal diameter substantiate the conclusions reached from the study of leaf area.

Inbreeding is accompanied by a marked and progressive loss of vigor in most of the lines studied. However, there is considerable variability in the response to inbreeding. Some inbred lines were found that showed no reduction in vigor when compared to their open-pollinated sibs and other inbred lines were so lacking in vigor that they failed to survive the first season.

Continued selection of late-maturing plants as maternal parents has not significantly changed time of maturity nor has inbreeding affected this character except in so much as it has reduced the vigor of many of the plants to the point that they were unable to produce heads. The inbred plants that were able to head did so at the same time as their open-pollinated sibs.

Seed production, as measured by the percentage of spikelets containing caryopses, has shown much variability that is apparently influenced by the genetic constitution of the plant. Seed set is greatly reduced following inbreeding and there are indications that this re-

duction is due to genetic factors rather than any abnormal condition within the bags. Germination has not been affected by inbreeding nor has the time of emergence of the seedlings varied significantly between open-pollinated and inbred sibs. Significant inter-annular correlations have been found for each of the characters—leaf area, number of culms, plant height, basal diameter, and time of maturity. Significant positive correlations of leaf area to number of culms and plant height were found, but leaf area and time of maturity exhibited no definite relationships. Also, there were no significant correlations between plant height and number of culms except in the unselected material.

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FIELD GERMINATION OF ALFALFA SEED SUBMITTED FOR REGISTRATION IN COLORADO AND VARYING IN HARD SEED CONTENT[1]

Ralph M. Weihing[2]

HARD or impermeable seeds which commonly occur in alfalfa are those that do not absorb water (swell) and germinate under laboratory conditions standard for determining germination of alfalfa seed. These seeds, for the most part, are alive and when planted in the field may produce healthy seedlings, but there are differences of opinion as to their agricultural value for planting. Since alfalfa seed offered for sale often contains high percentages of hard seeds, it is desirable to know the comparative planting value of seed containing high and low percentages of hard seeds.

The results of a study conducted under irrigation on the Agronomy Farm of the Colorado Experiment Station at Fort Collins, Colorado, to determine the agricultural value of alfalfa seed varying from 1 to 62% of hard seeds are presented in this paper.

LITERATURE

Harrington (1)[3] states, "A large proportion of impermeable alfalfa,. . . . seeds will germinate in the soil during the first few months after planting, some of them early enough to be of importance to the crop," and recommends, "To the percentage of germination add two-thirds of the percentage of impermeable seeds . . . . More than two-thirds of the impermeable seeds may germinate, but not soon enough to compete with weeds."

Leggatt (2) concluded that hard seed of alfalfa had practically the same value from the point of view of number of plants produced as had the permeable, although the permeable seeds gave more prompt germination. Lute (4) found that "Impermeable seeds have a considerable agricultural value when there is a very high impermeable seed content," "They do not increase the number of plants when only a few are present," and "They germinate more slowly than other seeds."

Whitcomb (6) says, "These results with alfalfa would seem to indicate that the hard seeds are of practically the same value as plant producers in the field as the ordinary seeds." He confirms this viewpoint in later papers (7, 8, 9). This investigator (10) later states, "Half the hard seeds may be safely added to the laboratory germination of alfalfa, ... for the purpose of interpretation of the field value of these seeds."

[1]Contribution from the Agronomy Section, Colorado Experiment Station, Fort Collins, Colo. Published with the approval of the Director as Scientific Series Paper No. 110. Received for publication September 30, 1940.

[2]Assistant Agronomist. For the first two years this study was conducted by Mr. John Spencer and Mr. Wayne Austin, formerly with the Colorado Seed Registration Service, and now with the Soil Conservation Service, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 949.

MATERIALS AND METHODS

The seed was obtained from samples submitted by Colorado seed growers to the Colorado Seed Registration Service. Laboratory germination tests of these samples were made by the Colorado State Seed Laboratory.[4] Seeds which did not swell after 6 days at 20° C between moist blotters were considered hard or impermeable, while percentage germination was based on sprouted seeds. Four hundred seeds of each sample were tested in the laboratory.

Seed from samples tested in the laboratory during the winter was planted the following spring in the field. Lute (5) from her studies made the following general conclusions: "One-half of the impermeable alfalfa seeds when kept in storage became permeable in three and one-half years" and "All impermeable seeds of alfalfa in storage became permeable in 11 years." This suggests that a few of the seeds found to be hard during the winter were permeable when planted in the field in the spring. Sixty-seven laboratory-tested samples which varied from 1 to 62% in hard seed content were planted in the field. Spring field plantings of 22, 27, 12, and 6 samples were made in 1932, 1933, 1938, and 1939, respectively.

Three hundred seeds of each sample were planted in the field 1 inch deep and 1 inch apart in rows 12 inches apart. The 300 seeds of each sample were planted in three plots (100 seeds in each plot) arranged at random within replications. In 1932 the number of plants was counted 10, 28, and 43 days after planting, and in 1933 similar counts were made 31 and 77 days after planting. This technic did not give true emergence of seedlings since some plants were killed by insects or other agencies before and between counting days. In 1938 and 1939 a small stake was placed beside each seedling shortly after emergence so that the actual number of seedlings which emerged was obtained even though some plants died before termination of the experiments.

The dates of planting were May 3, May 7, May 3, and April 28 in 1932, 1933, 1938, and 1939, respectively.

RESULTS

The data for six samples tested in the laboratory during the winter of 1938–39 and planted in the spring of 1939 are given in Table 1. The percentages of hard seeds varied from 14 to 54, but 10 days after planting, emergence of seedlings was nearly the same for all samples, varying from 54 to 62%. Seventeen days after planting, emergence

TABLE 1.—*Laboratory and field germination of alfalfa seed, 1939.*

Laboratory germination, winter of 1938–39			Field emergence of seedlings after		
Hard seeds, %	Germination, %	Total, %	10 days, %	17 days, %	35 days, %
14	80	94	62	69	70
22	74	96	62	64	64
30	63	93	54	60	65
41	54	95	56	66	74
49	45	94	55	65	68
54	41	95	54	62	66

[4]The tests were made by Anna M. Lute, Seed Analyst, Colorado Experiment Station.

varied from 60 to 69%. Thirty-five days after planting, emergence in the sample containing 14% of hard seeds exceeded that in the sample containing 54% by only 4%.

TABLE 2.—*Laboratory and field germination of alfalfa seed, 1938.**

Laboratory germination, winter of 1937–38			Field emergence of seedlings after					
Hard seeds, %	Germination, %	Total, %	8 days, %	14 days, %	22 days, %	28 days, %	36 days, %	48 days, %
1	96	97	36	70	73	73	73	74
15	76	91	23	52	55	55	55	60
25	58	83	24	48	51	51	52	57
28	63	91	18	45	50	51	51	57
30	57	87	27	51	57	57	58	61
34	58	92	25	54	60	62	62	70
35	59	94	23	48	53	54	54	61
38	55	93	24	55	61	62	62	66
44	49	93	15	48	53	55	55	61
47	47	94	19	44	50	51	52	61
52	43	95	19	47	53	54	54	65
55	44	99	16	49	54	56	56	61

*One irrigation 38 days after planting.

TABLE 3.—*Laboratory and field germination of alfalfa seed, 1933.*

Laboratory germination, winter of 1932–33			Plants in field after	
Hard seeds, %	Germination, %	Total live, %	31 days, %	77 days, %
5.5	85.0	90.5	47	47
8.0	82.0	90.0	43	38
9.0	86.0	95.0	51	45
13.0	77.0	90.0	49	45
25.5	66.0	91.5	40	36
29.5	69.0	98.5	58	54
30.5	61.0	91.5	33	41
32.0	60.5	92.5	41	37
33.0	56.5	89.5	55	47
34.5	61.5	96.0	54	45
37.5	57.5	95.0	38	33
38.0	52.5	90.5	47	45
39.0	54.0	93.0	45	43
39.0	56.5	95.5	55	48
40.0	57.0	97.0	52	44
42.0	49.5	91.5	44	40
43.5	49.5	93.0	41	39
44.5	43.5	88.0	46	42
44.5	46.5	91.0	48	43
47.0	54.5	91.5	36	33
48.0	48.0	96.0	53	48
49.0	46.5	95.5	36	31
49.5	39.0	88.5	45	44
53.0	47.0	100.0	45	38
57.5	39.0	96.5	47	41
61.0	36.0	97.0	39	39
62.0	29.5	91.5	46	46

Percentage of hard seeds in samples tested in the laboratory during the winter of 1937–38 and planted in the spring of 1938 varied from 1 to 55 (Table 2). At the end of the test, 48 days after planting, the number of emerged seedlings was highest for the sample containing 1% of hard seeds, but it was nearly equal for samples varying from 15 to 55% of hard seeds. However, emergence was more rapid in samples with few hard seeds than in samples with many hard seeds. By two weeks after planting, emergence was practically the same for nearly all samples.

The counts of plants 31 and 77 days after planting in 1933 (Table 3) show that all samples of seed produced about equal numbers of plants even though the samples varied in hard seed content from 5.5 to 62.0%. The 1932 field results (Table 4) show that 4 weeks after planting samples varying from 4 to 57.5% hard seeds produced about equal numbers of plants. Ten days after planting (Table 4) emergence was greater for samples with few hard seeds than for those with many. This advantage was lost 4 weeks after planting.

TABLE 4.—*Laboratory and field germination of alfalfa seed, 1932.*

Laboratory germination, winter of 1931–32			Plants in field after		
Hard seeds, %	Germination, %	Total, %	10 days, %	28 days, %	43 days, %
4.0	90.0	94.0	62	68	67
11.0	84.5	95.5	67	77	77
12.0	88.5	100.5	64	73	69
22.0	63.0	85.0	45	55	55
24.0	66.0	90.0	65	69	70
28.0	67.0	95.0	54	65	61
37.0	59.0	96.0	53	68	66
37.0	57.0	94.0	57	63	63
37.5	54.0	91.5	55	69	66
38.5	53.5	92.0	60	72	73
40.5	55.5	96.0	54	64	63
40.5	55.5	96.0	56	71	68
41.0	47.0	88.0	43	53	54
43.0	48.0	91.0	45	60	58
43.5	56.0	99.5	54	65	66
47.0	50.5	97.5	58	66	66
47.0	47.0	94.0	50	58	53
48.5	42.5	91.0	46	55	54
50.5	39.5	90.0	58	69	67
53.5	42.0	95.5	45	59	61
57.0	39.0	96.0	51	71	67
57.5	40.0	97.5	48	63	61

Plant counts were made in 1932 and 1933, while emergence records were made in 1938 and 1939. Since some seedlings and plants die in the field because of insect injury and other causes, the last plant count in the season may be lower than preceding ones. This actually happened in the two years, 1932 and 1933, that plant counts were made. The abnormally small number of plants in 1933 probably was caused by such injury. In 1938 and 1939 approximately 50% and 15%, respectively, of the plants died after emergence so that

plant counts in those years would have been 50% and 85% of the emergence values.

The data in Tables 1, 2, and 4 show that 70% emergence in the field rarely was exceeded, even though some samples germinated more than this amount in the laboratory. This observation has been made by other investigators so that it seems that 70% emergence is as much as can be expected even under favorable field conditions.

The data for the 4 years are summarized in Table 5 to show the percentage germination[5] in the field for samples which had 0 to 9%, 10 to 19%, 20 to 29%, 30 to 39%, 40 to 49%, and 50 to 62% of hard seeds in the laboratory tests. Samples with less than 20% of hard seeds germinated 61 to 64%, whereas samples with 20% or more hard seeds germinated 57 to 60% on the average. Slightly better germination can be expected in the field from seed with few hard seeds than from seed with many.

TABLE 5.—*The comparative field germination of samples of alfalfa seed varying from 1 to 62% of hard seed.*

Hard seed, %	1939*		1938*		1933†		1932‡		Germination, %	
	No. of samples	Germination, %	No. of samples	Germination, %	No. of samples	Germination, %	No. of samples	Germination, %	3-year av.	4-year av.
0–9	—	—	1	74	3	47	1	68	63	—
10–19	1	70	1	60	1	49	2	75	61	64
20–29	1	64	2	57	2	49	3	63	57	58
30–39	1	65	4	61	8	46	4	68	58	60
40–49	2	71	2	64	9	45	8	62	57	60
50–62	1	66	2	63	4	44	4	66	58	60

*Percentage germination based on total emergence for the season.
†Percentage germination based on plants present 31 days after planting.
‡Percentage germination based on plants present 28 days after planting.

SUMMARY AND CONCLUSION

The data show that samples of seed with 20 to 62% of hard seeds produced about equal numbers of plants in the field. These samples averaged 57 to 60% germination. Samples with less than 20% hard seeds averaged 61 to 64% germination, slightly higher germination than for samples containing 20% or more of hard seeds.

Emergence was more rapid for samples of seed with few hard seeds than for those with many, but 2 to 3 weeks after planting all samples had nearly equal numbers of plants.

The data indicate that under favorable field conditions not more than 70% emergence can be expected for samples of seed germinating nearly 100% in the laboratory.

Alfalfa seed containing many hard seeds has almost the same agricultural value for planting as alfalfa seed containing few hard seeds.

[5]Emergence in 1938 and 1939, number of plants 28 days after planting in 1932, and number of plants 31 days after planting in 1933.

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RELATIVE PRODUCTIVITY OF THE A HORIZON OF CECIL SANDY LOAM AND THE B AND C HORIZONS EXPOSED BY EROSION[1]

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THE Piedmont Plateau Soil Province of South Carolina comprises a considerable variety of soils of which the Cecil series is the most extensive and one of the most valuable for general farming. It is well adapted to the production of cotton which is the chief source of farm income in this area.

Cultivated areas of Cecil sandy loam, before being materially altered by erosion, have a yellowish-gray or grayish-brown surface soil and a red clay subsoil which is underlain by highly weathered, disintegrated granite or gneiss. The topography where these soils occur varies from undulating to rolling or hilly. The sloping terrain in combination with high rainfall (approximately 50 inches annually) and the use of farming methods conducive to accelerated erosion have resulted in extensive soil loss by water erosion. In some places these soils have eroded to such an extent that their agricultural value has been destroyed entirely.

There are large acreages of Cecil soils in which the A horizon has been removed entirely by erosion, leaving the red clay of the B horizon exposed. Fair crops are frequently produced on such areas, and it is possible in many places to improve them by additions of organic matter and the use of suitable farming practices to such an extent that high yields of crops can be obtained. There are also extensive areas on which both the A and the B horizons have been removed by erosion. When the A and B horizons are eroded they cannot be re-formed or replaced by practical agricultural methods. There remains only the highly unproductive weathered rock, which is not classed as a soil but only as the material from which one may be developed when subjected to soil-forming processes for a long period of time. Field observations of a qualitative nature have shown that erosion of the surface soil causes a decrease in productivity of Cecil soils, but there are no quantitative data available showing the extent of this relation.

Experiments designed to obtain some information regarding the relative productivity of different horizons of Cecil sandy loam were started near Moore, S. C., in 1935.

Twelve experimental areas, each 1/500 acre in size (10 feet by 8 feet, 9 inches), were marked off and excavated to a depth of 2 feet. Each area was enclosed in a creosoted board wall extending to the bottom of the excavation. Soil from the A horizon of Cecil sandy loam was collected from 40 different locations in the South Tyger River Project Area, transported to the desired location, placed in a pile, and mixed. The soil from the B horizon was collected and mixed in

[1]Contribution of the Soil Conservation Service, Office of Research, in cooperation with the South Carolina Agricultural Experiment Station, Clemson, S. C. Received for publication October 2, 1940.

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a similar manner. The soil in each case was obtained from areas where the horizon desired had been exposed to the atmosphere for a considerable period of time, that is, the B horizon was obtained where the A horizon had already been removed by erosion. The C horizon material was likewise collected from a number of locations where it had been exposed for a considerable length of time. There were four plots for each horizon. The A horizon plots were prepared by placing 12 inches of B horizon material on the bottom of each pit and 12 inches of A horizon material on top of it. The B horizon plots contained only B horizon material and the C horizon plots only C horizon material or weathered rock. All plots were prepared during the summer of 1935.

In the spring of 1936 these plots were fertilized at the rate of 400 pounds per acre of 4–12–4 fertilizer and planted to cotton. The fertilizer was applied under the beds prior to planting. Each plot contained the same number of rows and received the same treatment. The cultural treatments received by the plots were similar to those practiced by farmers in this area. Photographs of these plots taken the latter part of August (Fig. 1) show the relative cotton growth on the plots of each horizon.

In 1937, 1938, and 1939 all plots were again planted to cotton with an annual fertilizer application of 400 pounds per acre of 4–8–4 in 1937 and 4–10–4 in 1938 and 1939. In addition to the fertilizer application in 1939, two plots of each horizon received manure at the rate of 4 tons per acre. The manure was broadcast over the plots the same day the cotton was planted. The annual yields of seed cotton and the averages for the 4-year period are given in Table 1.

TABLE 1.—*Productivity of different horizons of Cecil sandy loam as determined by cotton yields at Moore, S. C.*

Horizon	Yield of seed cotton per acre, pounds*				
	1936	1937	1938	1939	Average
A	1,610	1,241	345	561	939
B	235	501	132	348	304
C	75	113	83	51	81

*These data are averages of four plots for each horizon with the exception of 1939 when only the two plots of each horizon not receiving manure were included.

The results show wide variations in yield from year to year within each horizon which were undoubtedly influenced to a great extent by seasonal conditions. The low yields of the A horizon after 1936, however, indicate that the soil decreased in productivity during the experiment. Yields on the B and C horizons were low at the beginning of the experiment and remained so throughout the test. If the 4-year average yield of the A horizon is compared with the yield from the B horizon, a difference of 635 pounds of seed cotton is noted in favor of the A horizon plots. Likewise, the A horizon showed an average yield of 858 pounds more of seed cotton than the C horizon. The average yield for the B horizon was 223 pounds more than the C

horizon. The results of this study emphasize the importance of conserving the A horizon of surface soil for farming purposes. The low

FIG. 1.—Growth of cotton on A, B, and C horizons (reading from the top down) of Cecil sandy loam in August 1936.

yields from the B and C horizons were probably due largely to lack of an adequate supply of nitrogen and other nutrients, as the soil of these horizons is very infertile until improved by suitable farming practices.

The influence of stable manure upon cotton yields on the A, B, and

TABLE 2.—*Cotton yields on different horizons of Cecil sandy loam, showing the influence of manure in 1939 following three years of continuous cotton without manure.**

Horizon	Plot Nos.	Treatment	Yield of seed cotton per acre, pounds 1936	1937	1938	Treatment†	Yield of seed cotton per acre in 1939, pounds
A	1 and 3	Unmanured	1,536	1,227	356	Manured	845
	2 and 4	Unmanured	1,684	1,254	335	Unmanured	561
B	1 and 3	Unmanured	242	461	89	Manured	501
	2 and 4	Unmanured	228	541	175	Unmanured	348
C	1 and 3	Unmanured	106	131	105	Manured	426
	2 and 4	Unmanured	44	188	61	Unmanured	51

*All plots received inorganic fertilizer each year.
†The manure treatments in 1939 were at the rate of 4 tons per acre.

TABLE 3.—*Boll counts of cotton grown on different horizons of Cecil sandy loam, showing the percentage open on October 28, 1936, as an index of earliness of maturity.*

Horizon	Plot No.	Bolls per plot, number	Open bolls per plot on Oct. 28 Number	%
A	A-1	247	76	30.8
	A-2	321	142	44.3
	A-3	326	152	46.6
	A-4	304	175	57.6
Average		300	136	45.3
B	B-1	73	0	0.0
	B-2	110	2	1.8
	B-3	127	1	0.8
	B-4	104	6	5.8
Average		104	2	1.9
C	C-1	52	10	19.2
	C-2	50	2	4.0
	C-3	36	2	5.6
	C-4	28	2	7.1
Average		37	4	10.8

C horizons of Cecil sandy loam is shown in Table 2. The manure caused a substantial increase in cotton yields on all horizons, but its effect was most pronounced on the C horizon. In Table 2 the plots have been arranged in duplicate for each year, corresponding to the manure-treated plots of 1939. The manure had a beneficial effect on the survival of plants on the C horizon but did not noticeably affect the survival of cotton plants on the other horizons.

Data in Table 3 were collected in order to obtain some idea as to the number of bolls produced and the earliness of maturity which is important under boll weevil conditions. The cotton bolls opened earlier on the A horizon than on the B or the C horizons. Practically one-half, or 136 bolls, on the A horizon were open October 28 when the counts were made, as compared with two and four open bolls on the B and C horizons, respectively.

SUMMARY

In summarizing the results it may be stated that under the conditions of this experiment the A horizon was more than 3 times as productive as the B and 11 times as productive as the C horizon. Additions of organic matter in the form of stable manure resulted in increased yields on all horizons. The beneficial effect of manure on the C horizon was relatively greater than on the other horizons.

The results from the manure treatments indicate that the productivity of eroded Cecil soils may be greatly improved through the addition of organic matter and an adequate supply of plant nutrients.

GENETICS OF CROSS-INCOMPATIBILITY AMONG SELF-INCOMPATIBLE PLANTS OF *TRIFOLIUM REPENS*[1]

SANFORD S. ATWOOD[2]

A KNOWLEDGE of the genetics of cross-incompatibility is of fundamental interest in any species and should be one of the first prerequisites to the intelligent planning and pursuing of a practical breeding program. This character has been investigated in a large number of species, as reviewed by Stout (5),[3] but only Williams (6) has made extensive observations with white clover. He reported (a) that unrelated plants generally are reciprocally cross-compatible, (b) that sister plants are either reciprocally cross-incompatible (c. 26% of his crosses) or reciprocally cross-compatible, and (c) that compatible F_1 sister crosses on the average seemed to produce as many seeds as crosses between unrelated plants.

MATERIALS AND METHODS

The original parents used in this investigation were two highly self-incompatible plants, one of which came from a seed lot collected in Michigan while the other was clonally isolated from a pasture in Pennsylvania. The cross between these two plants was made in the greenhouse during the winter of 1937–38, and the F_1 was grown in the field the following summer at which time 13 plants were selected for greenhouse study. These plants were similar to their male parent in having a solid white area on their leaflets, thus indicating that they were legitimate hybrids, since the marking is dominant over the solid green color of the female. The principal basis for selection among both F_1 and F_2 plants was their general vigor and paucity of disease. Also, wherever possible, plants were chosen which flowered well in the field, since it had been observed in the winter of 1937–38 that the plants which flowered best in the greenhouse were those plants which had flowered well the summer before in their first year's growth in the field. Practically all the controlled cross-pollinations were made in screened greenhouses during the winter. The technics used for emasculating and pollinating, as well as those for cross-pollination with bees and for self-pollination under bag, will be described in another publication.

EXPERIMENTAL RESULTS

The two parents and their F_1 were self-pollinated in several ways (tripping 10 flowers per head, with and without emasculation, and rubbing entire heads) and at different times to measure their self-compatibility. The largest average number of seeds set on one parent under all treatments was 1.8 per head and on the other 1.6. A similar degree of self-compatibility was shown by 14 F_1 plants, which yielded

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[2]Agent.

[3]Figures in parenthesis refer to "Literature Cited", p. 968.

TABLE 1.—*Number of seeds set per 10 flowers in all reciprocal combinations between 13 self-incompatible sister plants (1–3 to 1–15) resulting from the previous cross between a self-incompatible female (1–1) and male (1–2) parent, together with the reciprocal back-crosses of each F_1 plant with both parents.*

		♂															
Genotype	Plant No.	1–I (S_1S_2)	1–II (S_3S_4)	1–III (S_1S_3)					1–IV (S_2S_3)				1–V (S_1S_4)			1–VI (S_2S_4)	Average of compatible crosses
		1–1	1–2	1–3	1–4	1–5	1–7	1–9	1–10	1–11	1–13	1–15	1–8	1–12	1–14	1–6	
1–I(S_1S_2)	1–1	0	51	42	48	47	45	(50)*	43	44	43	46	45	(39)	48	49	45.7
1–II(S_3S_4)	1–2	52	0	50	47	52	51	51	51	47	50	46	54	(49)	53	(51)	50.3
	1–3	47	51	0	0	0	3†	1†	48	55	52	38	51	54	43	51	49.0
	1–4	42	41	0	0	0	0	0	35	41	43	43	(47)	41	48	37	41.8
♀ 1–III(S_1S_3)	1–5	30	43	0	0	0	0	1†	35	36	(41)	39	38	43	31	38	37.4
	1–7	46	46	0	0	2†	2	0	51	44	50	42	50	42	(41)	43	45.5
	1–9	46	39	0	0	1†	0	1†	37	45	42	47	35	49	38	43	42.1
	1–10	40	38	36	41	32	36	39	0	1†	0	0	36	(41)	39	40	38.0
1–IV(S_2S_3)	1–11	51	14	48	46	52	47	44	0	0	0	0	51	53	44	42	47.8‡
	1–13	50	43	46	(50)	45	43	48	1	0	1†	1†	48	50	47	54	47.6
	1–15	45	40	49	48	46	40	44	0	0	0	2†	45	44	41	43	44.1
	1–8	48	51	42	54	49	48	54	52	47	(50)	51	1†	2†	0	47	49.4
1–V(S_1S_4)	1–12	41	(40)	36	28	(33)	41	35	28	36	37	31	0	0	0	38	35.3
	1–14	(38)	53	55	54	49	49	53	48	49	52	46	2†	4†	0	(49)	49.6
1–VI(S_2S_4)	1–6	49	45	55	45	49	44	46	50	48	46	47	48	48	42	1†	47.3
																	44.9‡

*Numbers in parenthesis in this and the following tables recording seed set have been adjusted to a 10-flower basis. For instance, if a pod was lost at harvesting, the total number of seeds obtained was increased by 1/9. In no case have less than eight flowers been available.

†Duplicate cross yielded 0 seed.

‡The seed set in cross 1–11 × 1–2 was omitted from average. This is abnormally low because of poor pollination. The duplicate cross was lost.

	1–III	1–IV	1–V	1–VI	Total
Expected	3.25	3.25	3.25	3.25	13
Obtained	5	4	3	1	

from 246 heads under bag in the field an average seed-set of 1.7 per head and whose individual averages ranged only from 0.6 to 4.6. Very few white clover plants have been found which will not yield an occasional seed when a large number of heads are selfed. On the other hand, plants have been found which are just as self-compatible as they are cross-compatible. Comparatively speaking, the plants used in this investigation may be considered practically self-incompatible.

TABLE 2.—*Number of seeds set per 10 flowers when F_2 plants from cross 1–III × 1–IV (1–7 × 1–11) were back-crossed to P and F_1 groups.*

Genotype	Plant No.		1–I (S_1S_2)	1–II (S_3S_4)	1–III (S_1S_3)	1–IV (S_2S_3)	1–V (S_1S_4)	1–VI (S_2S_4)	Average of compatible crosses
1–I(S_1S_2)	1–17	♀	0	50	51	55	52	53	52.2
		♂	0	(42)	30	49	43	47	
	1–20	♀	0	44	43	40	40	28	39.0
		♂	0	—	—	—	—	—	
	1–23	♀	0	51	(47)	41	49	57	49.0
		♂	0	31	43	34	36	—	
	1–86	♀	3	50	38	33	—	—	40.3
		♂	0	40	45	38	48	—	
	1–90	♀	—	—	—	—	—	—	—
		♂	0	—	23	19	—	—	
1–IV (S_2S_3)	1–16	♀	39	46	39	0	36	32	38.4
		♂	—	—	—	0	—	—	
	1–18	♀	34	36	33	0	26	33	32.4
		♂	—	—	—	0	—	—	
	1–19	♀	24	22	15	0	29	31	24.2
		♂	—	—	—	0	—	—	
	1–21	♀	47	50	28	0	37	52	42.8
		♂	46	—	—	2	—	—	
	1–22	♀	33	35	21	0	28	31	29.6
		♂	—	—	—	0	—	—	
	1–24	♀	31	47	34	0	42	35	37.8
		♂	—	—	—	0	—	—	
	1–25	♀	53	32	44	0	40	50	43.8
		♂	—	—	—	0	—	—	
	1–87	♀	43	34	—	0	—	—	38.5
		♂	48	48	38	1	37	51	
Average of compatible crosses			47.0	40.2	35.8	35.0	41.0	49.0	39.2

	1–I	1–IV	Total
Expected:	6.5	6.5	13
Obtained:	5	8	

The 13 selected F_1 plants consisted of four intra-sterile, inter-fertile groups of five, four, three, and one, respectively, and every F_1 plant was reciprocally fertile with both parents (Table 1). Every combination was made in duplicate, and a few were made three or

TABLE 3.—*Number of seeds per 10 flowers when F_2 plants from cross 1-III × 1-V (1-7 × 1-8) were backcrossed to P and F_1 groups.*

Genotype	Plant No.		1-I (S_1S_2)	1-II (S_3S_4)	1-III (S_1S_3)	1-IV (S_2S_3)	1-V (S_1S_4)	1-VI (S_2S_4)	Average of compatible crosses
	1-26	♀	2*	1	41	50	50	49	47.5
		♂	44	0	44	40	48	30	
	1-27	♀	0*	1	0*	0*	0*	0*	—
		♂	—	0	—	—	—	—	
	1-28	♀	41	0	43	40	51	58	46.6
		♂	48	0	51	48	46	42	
	1-30	♀	46	0	40	0*	28	0*	38.0
		♂	—	0	—	—	—	—	
	1-31	♀	46	0	0*	1*	(23)	44	37.7
		♂	—	1	—	—	—	—	
1-II (S_3S_4)	1-32	♀	0*	0	40	0*	39	18	32.3
		♂	—	1	—	—	52	—	
	1-33	♀	20	0	23	34	39	49	33.0
		♂	47	0	28	40	52	—	
	1-91	♀	—	0	—	—	—	—	—
		♂	44	1	40	49	52	—	
	1-93	♀	0*	0	23	36	—	—	29.5
		♂	51	0	41	48	49	—	
	1-94	♀	(8)*	0	—	18	10	—	14.0
		♂	—	0	—	lost*	24	—	
	1-95	♀	16	0	30	20	37	29	26.4
		♂	46	0	32	(50)	47	46	
	1-29	♀	44	53	45	46	0	34	44.4
		♂	43	—	—	—	0	—	
I-V(S_1S_4)	1-34	♀	30	41	51	49	1	51	44.4
		♂	—	—	—	—	0	—	
	1-35	♀	48	50	47	45	0	13*	47.5
		♂	—	—	—	—	1	—	
Average of compatible crosses			46.1	—	40.7	45.8	46.2	39.3	40.6

*Cross was recorded compatible by reflection of pedicels on third day after pollination. This abnormally low seed set was omitted from average for plant.

	1-II	1-V	
Expected:	7	7	14
Obtained:	11	3	

four times, but only the higher or highest seed-set is shown in the table. The largest number of seeds obtained was considered to measure most accurately the true potentialities of a combination, any lower number probably resulting from poor pollination or from damage during crossing rather than from reduced compatibility. In every combination, the same type of results was obtained from the duplicates which generally were made by different persons at intervals ranging up to seven weeks. Although there was usually some variation between the duplicates in the exact number of seeds, there was generally no question as to whether a particular cross was compatible or incompatible. The average of the higher seed set in these compatible combinations was 44.9 per 10 flowers crossed, whereas the average obtained from the 114 incompatible crosses and selfs that were made, including duplicates, was 0.26 seed. It will be shown below that in a sample of these seeds from incompatible crosses approximately half resulted from contamination, so that the ratio between compatible and incompatible crosses in average seed-set is really twice as large as these numbers indicate. A similar difference between compatible and incompatible crosses in average seed-set was found among the F_2 matings (Tables 2, 3, 4, and 5).

These compatibility relationships seem to be explained best by the diploid personate type of multiple oppositional factors. This hypothesis was first presented with substantiating data by East and Mangelsdorf (3), using *Nicotiana*, and has since been applied to several other species. According to the theory, if a pollen grain carries the same allelomorph as one of those in the pistil, the resulting pollen tube fails to grow far enough to allow fertilization. On the other hand, if a pollen grain bears an allelomorph different from either of those in the pistil, pollen-tube growth is normal and fertilization is brought about. Incompatibility would be expected only in crosses between plants of the same genotype. Compatibility would result in crosses between plants differing in one or both factors, the progeny consisting respectively of two or four genotypes. The latter alternative appears to have been the condition shown in Table 1:

$$\begin{array}{lcccc} & & \text{I} & & \text{II} \\ \text{P} & & S_1S_2 & \times & S_3S_4 \\ & & & \downarrow & \\ & \text{III} & \text{IV} & \text{V} & \text{VI} \\ \text{F}_1 & S_1S_3 & + S_2S_3 & + S_1S_4 & + S_2S_4 \end{array}$$

Since all four genotypes are different from those of the parents, all backcrosses should be reciprocally compatible (Table 1).

The four progeny genotypes, together with those of the two parents, constitute the six possible paired combinations of the four allelomorphs brought together from the two parents. On this interpretation can be based a progeny test (a) to check the applicability of the theory in predicting F_2 results and (b) to establish a certain genotype for each parental and F_1 group. The test consisted of crossing one F_1 group as a female with each of the other three groups. From one of these crosses, the F_2 should consist of equal numbers

TABLE 4.—*Number of seeds set per 10 flowers when F_2 plants from cross 1-III × 1-VI (1-7 × 1-6) were backcrossed to P and F_1 groups.*

Genotype	Plant No.		1-I (S_1S_2)	1-II (S_3S_4)	1-III (S_1S_3)	1-IV (S_2S_3)	1-V (S_1S_4)	1-VI (S_2S_4)	Average of compatible crosses
1-I (S_1S_2)	1-36	♀ ♂	0 0	34 —	30 —	27 —	41 —	15 —	29.4
	1-37	♀ ♂	0 0	36 —	38 —	35 —	34 —	32 —	35.0
	1-39	♀ ♂	0 0	24 —	13 —	0* —	29 —	30 —	26.2
1-II (S_3S_4)	1-40	♀ ♂	42 —	0 0	43 —	33 —	39 —	41 —	39.6
	1-43	♀ ♂	37 —	0 2	40 —	27 —	30 —	31 —	33.0
1-IV (S_2S_3)	1-44	♀ ♂	34 —	30 —	23 —	0 0	31 —	20 —	27.6
1-V (S_1S_4)	1-38	♀ ♂	51 55	58 25	52 43	46 51	15† 0	53 39	52.0
	1-41	♀ ♂	21 —	32 —	23 —	31 —	0 0	30 —	27.4
	1-42	♀ ♂	39 —	33 —	27 —	35 —	0 0	11 —	29.0
	1-45	♀ ♂	55 —	34 —	35 —	33 —	0 0	50 —	41.4
	1-97	♀ ♂	24 39	22 0*	33 39	27 50	0 0	— 30	26.5
	1-98	♀ ♂	— 46	— 10*	21 40	32 49	0 0	— 32	26.5
Average of compatible crosses			46.7	25.0	40.7	50.0	—	33.7	34.8

*Cross was recorded compatible by reflection of pedicels on third day after pollination. This abnormally low seed set was omitted from average for plant.

†Cross was recorded as incompatible by no reflection of pedicels on third day after pollination. All 15 seeds were badly shrunken.

	1-I	1-II	1-IV	1-V	
Expected:	3	3	3	3	12
Obtained:	3	2	1	6	

of the group used as male and the group of the original female parent. From a second cross, the F_2 should consist of equal numbers of the group used as male and the group of the original male parent. And from the third cross, the F_2 should consist of equal numbers of the two F_1 groups not involved in this cross and the groups of both original parents. Following the designation used above, the results should be as follows:

$$\begin{array}{ccccc} \text{III} & & \text{IV} & & \text{I} \quad \text{IV} \\ S_1S_3 & \times & S_2S_3 & \longrightarrow & S_1S_2 + S_2S_3 \end{array}$$

$$\begin{array}{ccccc} \text{III} & & \text{V} & & \text{V} \quad \text{II} \\ S_1S_3 & \times & S_1S_4 & \longrightarrow & S_1S_4 + S_3S_4 \end{array}$$

$$\begin{array}{ccccc} \text{III} & & \text{VI} & & \text{I} \quad \text{V} \quad \text{IV} \quad \text{II} \\ S_1S_3 & \times & S_2S_4 & \longrightarrow & S_1S_2 + S_1S_4 + S_2S_3 + S_3S_4 \end{array}$$

In order to assign genotypes to the six groups, the four genes in the two original parents must be designated somehow and one of these genes from each parent must be arbitrarily assigned to one of the F_1 groups. The genotypes of the other three F_1 groups are then defined on the basis of progeny obtained when crossed with this one group. For example, following the designation shown above, if the group used as female for the three F_1 intercrosses is called III (S_1S_3), group IV (S_2S_3) is defined as the one which yields groups I and IV when crossed with III and which differs from III in the gene obtained from the original female parent (S_1S_2). Group V (S_1S_4) is defined as the one which yields groups II and V when crossed with III and which differs from III in the gene obtained from the original male parent (S_3S_4). Group VI (S_2S_4) is defined as the one which yields groups I, II, IV, and V when crossed with III and which differs from III in both genes.

When 39 F_2 plants from the three F_1 intercrosses were tested by backcrossing to representative plants from the two parental and four F_1 groups, only the expected groups were obtained (Tables 2, 3, and 4). Not all possible reciprocal combinations were made, but there were enough crosses with every plant to be certain of its genotype. The most critical crosses in every case involved (a) the reciprocal matings with the group with which a plant failed in order to check for possible homozygous genotypes and (b) matings with the other group or groups expected in that progeny in order to check for any unexpected failures due to disease or other environmental influences. The fact that only expected groups were obtained from all three crosses appears to prove the validity of the diploid personate theory as an explanation of cross-incompatibility in these plants of white clover. A comparison of expected and obtained, as given below the tables, indicates satisfactory agreement.

A material aid in carrying through the work was the fact that a pollination on to any plant could be predicted as compatible or incompatible by the behavior of the flowers subsequent to pollination. Within 20 to 24 hours after pollination the first differences could be observed. Following compatible crosses the standards and wings folded tightly around the keels, while they stayed unchanged after incompatible crosses. An even more distinct difference was seen in the degree of pedicel reflection 60 to 72 hours after pollination. After an incompatible cross, the pedicels stayed in approximately the same position as at pollination and there was no discoloration of the petals (Fig. 1). After a compatible cross, the pedicels became completely reflexed and the petals began to wither and turn brown

TABLE 5.—*Number of seeds per 10 flowers when homozygous plants were backcrossed to P and F_1 groups.*

Genotype	Plant No.	Parental group	Origin*		1–I (S_1S_2)	1–II (S_3S_4)	1–III (S_1S_3)	1–IV (S_2S_3)	1–V (S_1S_4)	1–VI (S_2S_4)	Average of compatible crosses
	1–46	1–III	A	♀	48	40	40	54	44	47	45.5
				♂	1	50	0	48	0	51	
	1–47	1–III	A	♀	38	22	44	35	36	34	34.8
				♂	1	6†	1	51	0	40	
S_1S_1	1–58	1–V	A	♀	—	—	—	—	44	—	44.0
				♂	0	37	1	53	1	51	
	1–61‡	1–V	A	♀	—	—	—	—	25	—	25.0
				♂	0	0†	0	0†	1	2†	
	1–84	1–V	B	♀	—	—	—	—	57	—	57.0
				♂	0	(45)	0	51	0	48	
S_2S_2	1–52	1–IV	A	♀	13	12	16	15	15	12	13.8
				♂	0	(36)	37	2	32	1	

S_3S_3	1–49	1–III	A	♀	37	33	26	28	22	5†	29.2
				♂	8‡	0	0	0	37	17	
	1–51	1–IV	A	♀	28	0†	33	0†	29	4†	30.0
				♂	50	10	5	5	40	48	
	1–67	1–III	B	♀	44	33	38	38	33	42	38.0
				♂	44	0	0	2	36	52	
	1–73	1–IV	C	♀	—	—	—	26	—	—	26.0
				♂	22	0	0	1	39	41	
	1–77	1–IV	C	♀	—	—	—	40	—	—	40.0
				♂	54	0	0	0	49	32	
S_4S_4	2–77	2–IV	B	♀	—	—	—	—	—	—	
				♂	52	0	38	52	0	1	
Average of compatible crosses					44.4	42.0	37.5	51.0	38.8	42.2	37.1

*A = Incompatible cross in greenhouse; B = Self-pollination under bag in field; C = Incompatible cross under bee cage in field.
†Cross was recorded compatible by reflection of pedicels on third day after pollination. This abnormally low seed set was omitted from average for plant.
‡Plant was effectively male sterile. The anthers were very hard and did not dehisce when the flowers were tripped. The pollen was poor after it was crushed out of the anthers.

(Fig. 2). The head shown in Fig. 1 yielded no seed, while that shown in Fig. 2 yielded 41 seeds (the duplicate of this cross, listed in Table 1, yielded 42).

When part of the flowers on a head were pollinated with compatible pollen and the rest with incompatible pollen for controlled cytological studies of pollen-tube growth, these differences in withering of petals and reflexing of pedicels were just as evident. Several days after pollination the flowers used in incompatible crosses slowly withered and the pedicels bent over, but even then the heads did not appear the same as those in compatible crosses, since the latter soon became fleshy throughout as the pods developed, while the former dried up and only infrequently ripened any seeds. A few crosses yielded no seed after they had been predicted as compatible, but in every case mechanical injury or disease, especially virus, had been recorded, which probably explained the failure. Most cases of reduced seed production were correlated with a note that not all of the flowers had reflexed, probably due to improper pollination. Since this observation on pedicel reflections appeared to be reliable, only a few of the crosses with the F_2 plants were made in duplicate. In fact, the reaction was so distinct with the plants tested for homozygosity that some of them were considered heterozygous and not crossed further, solely on the basis of these notes, a procedure which proved justified when the seed yield was obtained.

A few seeds were obtained from the incompatible crosses and self-pollinations made in the greenhouse on the F_1 plants. Similarly, a few were obtained in the field from self-pollinations under bag and from incompatible crosses under bee cages. According to the personate theory, there is a 1 :1 chance of these plants being homozygous, as indicated below:

$$\begin{gathered} S_1S_3 \text{ Selfed} \\ \downarrow \\ S_1S_1 + 2\ S_1S_3 + S_3S_3 \end{gathered}$$

Homozygous plants should be compatible as females with all six groups, but as males they should be incompatible with all groups possessing the gene for which they are homozygous, as follows:

$$\begin{gathered} S_1S_1 \times S_1S_2 \longrightarrow S_1S_2 \\ S_1S_2 \times S_1S_1 \longrightarrow 0 \end{gathered}$$

The four homozygous genotypes can be distinguished by the groups with which they fail to set seed, as follows: S_1S_1—fails as male with I, III, and V. S_2S_2—fails as male with I, IV, and VI. S_3S_3—fails as male with II, III, and IV. S_4S_4—fails as male with II, V, and VI.

With all homozygous plants obtained, the reactions were as expected (Table 5). Only three of the four possible homozygous genotypes were found in this series, but the fourth has been secured from another series of unrelated plants. When 37 plants were tested in this way, 11 were homozygous, 7 heterozygous, and 19 contami-

nants (Table 6). The contaminant plants had other genotypes than those expected on the basis of the groups from which they arose and probably resulted from accidental cross-pollination. Apparently considerable error was possible in the pollination technic when making incompatible crosses or selfs, but the fact that there were no contaminants in either the F_1 or F_2 from compatible crosses indicates that there was much less chance for error when making these. As pointed out above, another conclusion drawn from the presence of only 18 legitimate offspring among the 37 plants is that their parents must have been about half as self-compatible as they were first thought to be, which effectively doubles the ratio of average seed set between compatible and incompatible crosses.

FIG. 1.—Flowers 72 hours after incompatible cross 1–7 × 1–9. ×2.

In order to test whether certain combinations which were compatible or incompatible in the greenhouse would give the same results with bee pollination in the field, cages were set up over two or three plants. (The technic will be described in another publication). From two compatible crosses with this series of plants, about 80 and 90 times as much seed, respectively, was obtained as from the incompatible cross. These differences are not of quite the same magnitude as those obtained in the greenhouse with hand pollination, but they are certainly of practical significance.

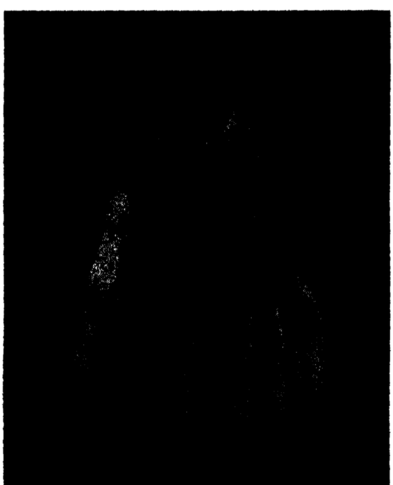

FIG. 2.—Flowers 72 hours after compatible cross 1–7 × 1–12, made at the same time and on the same plant as the head shown in Fig. 1. ×2.

In another series of plants involving one highly pseudo-self-compatible parent, the cross-incompatibilities appear to be interpretable on the same diploid personate theory (1). All evidence from crossing both related and unrelated plants indicates that there must be a large number of multiple allelomorphs causing incompatibility in white clover.

The cytological basis for these incompatibilities has been found to be poor pollen germination and pollen-tube growth both on

TABLE 6.—*Summary of homozygous test.*

Parental group	Homozygous	Heterozygous	Contaminants	Total
1–III	4	2	7	13
1–IV	4	4	2	10
1–V	3	1	9	13
1–VI	—	—	1	1
Total	11	7	19	37

	Homozygous	Heterozygous	
Expected:	9	9	18
Obtained:	11	7	

the stigma and in the style. Since this reaction takes place within a few hours after pollination, practically no tubes reach the ovary. The difference in behavior between compatible and incompatible pollen is so distinct that by examination of smeared stigmas, it is possible to distinguish pollinations in which the plants differ in two, one, or no factors. These results will be reported in detail later.

Another genetic observation in this study concerns the average number of seeds set in compatible crosses. These values are probably most accurate in Table 1 where the most crosses per plant are recorded and where nearly all crosses were made at least in duplicate. The seed-set on the original female parent, 1–1, ranged from 39 to 51 and averaged 45.7, while that on the male parent, 1–2, ranged from 46 to 54 and averaged 50.3. The F_1 varied from an average of 35.3 on plant 1–12 to 49.6 on plant 1–14. Although this entire range was not represented among the F_1 plants selected as parents of the F_2, the averages obtained among the different F_2 families were correlated with those of their F_1 parents. Apparently this character is inherited and may be conditioned by several genes, for which the original parents were probably heterozygous. The plant with the best seed-set of all those tested was from another series. Although used in only five crosses, an average seed-set of 62.0 was obtained. Plant 1–52 (Table 5) yielded the lowest average seed-set of 13.8. A cytological examination of pistils from representative plants in this range, both before fertilization and during embryo development, indicated that the principal factor influencing this difference was the number of ovules borne by the different plants. By removing all but 10 flowers from a head, the extra food available was probably a factor in causing ovules which otherwise might have aborted to develop into good seeds. Consequently, the number of seeds set per flower in these controlled crosses is a measure of the number of ovules produced. Some abortion takes place in the field on entire heads, where an average seed-set of over two per pod is found only occasionally even with the highest producing open-pollinated heads. Despite these differences in ovule abortion between greenhouse and field, a significant correlation ($r=.875$, $P<.01$) was found between the average seed-set per 10 flowers in the greenhouse and the average seed-set per head under bee cages in the field, based on the 25 best heads harvested from each of seven plants used in compatible crosses. Apparently these differences in number of ovules produced may be

of practical significance and should be considered in a breeding program.

DISCUSSION

A difference in seed yield between compatible and incompatible crosses has been the most common method used to distinguish these reactions, but with some species an arbitrary class limit has been used to separate the two kinds of crosses and in some cases the classes have overlapped. In white clover, no such difficulties occur, the seed yield being an excellent measure of compatibility. The two classes are very distinct and practically no overlapping occurs. In several groups of crosses the average yield from the compatible crosses was hundreds of times as great as from the incompatibles. These differences were dependent on the precision with which emasculation and pollination were done, but the technics were not difficult to learn or to execute.

Emerson (4) reported that direct tests of pollen-tube development as seen in smeared stigmas of *Oenothera organensis* were more reliable in determining cross-incompatibilities than failures in seed production. A similar technic for stigma smears has proved satisfactory for white clover. This species is distinctive in the speed and finality with which this reaction takes place on the stigma. By this procedure it can also be determined whether two compatible plants differ in one or both factors simply by observation rather than by a progeny test.

There was found, however, in white clover a much simpler and more reliable method for predicting seed yields than the direct tests of pollen-tube development. The degree of pedicel reflection on the third day after pollination provided a measure of compatibility which worked reliably with every plant and which was practically uninfluenced by diseases or other environmental factors. These observations were used instead of making duplicate crosses in order to check on reduced seed production or unexpected seed yields.

Incompatibility in white clover has been interpreted according to the diploid personate theory, but the plants used in this study were tetraploids. Root tips from representative F_1 plants were all found to have the regular somatic number of 32. When meiosis was studied in the microsporocytes of 11 plants of white clover (2), including the original female parent of the plants used in this investigation, it was found that the 32 chromosomes regularly associated as 16 bivalents. It was concluded that white clover is probably an amphidiploid, rather than an autotetraploid and that disomic segregation should be expected. Since a disomic segregation has been obtained for the multiple allelomorphs conditioning cross-incompatibility, it may be inferred that these allelomorphs are present in only one of the two genomes found in white clover.

SUMMARY

When the plants used in this investigation were self-pollinated in several ways and at different times, the seed-set was so low that all were considered practically self-incompatible.

Thirteen F_1 plants consisted of four intra-sterile, inter-fertile groups of five, four, three, and one plant, respectively, and all were reciprocally compatible with both parents. Using 10 flowers in each mating, compatible crosses averaged 44.9 seeds and incompatible 0.26.

These results are best explained by the diploid personate type of multiple oppositional allelomorphs (3), where the parents differed in both factors.

To check further the applicability of this theory to white clover and to establish a certain genotype for each parental and F_1 group, 39 F_2 plants from three F_1 intercrosses were tested by backcrossing to the two parental and four F_1 groups, and only the expected groups were obtained.

When 37 plants from incompatible crosses and selfs were tested by backcrossing to the two parental and four F_1 groups, 11 were homozygous, 7 heterozygous, and 19 contaminants. Three of the four possible homozygous genotypes were among these 11, and the fourth was obtained from an unrelated series of plants.

Within 20 to 72 hours after pollination, crosses on to any plant could be predicted as compatible or incompatible by the withering of the petals and the reflexing of the pedicels.

The number of seeds set per flower in compatible crosses is a measure of the number of ovules produced, and this character appeared to be inherited. Plants have averaged from 13.8 to 62.0 seeds per 10 flowers, and these differences in seed set in the greenhouse were significantly correlated in the seven plants tested ($r = .875$, $P < .01$) with the seed set under bee cages in the field.

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YIELDS OF KOREAN LESPEDEZA AS AFFECTED BY DODDER[1]

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IN MANY sections where the annual lespedezas are grown, common dodder (*Cuscuta pentagona* Engel.) is found as a parasite on the lespedeza. Dodder is usually considered a noxious weed, and in spite of control measures that have been attempted, apparently is becoming more widely distributed from year to year. Questions often arise as to the effect of dodder on the hay and seed yields of lespedeza and on the relative feeding value of dodder-infested hay. It is desirable, therefore, that more information on the subject be made available.

During the season of 1939, square yard areas of adjacent infested and non-infested Korean lespedeza were harvested at Statesville, N. C. As the dodder was located in scattered spots from 10 to 30 feet in diameter, it was possible to obtain infested and non-infested paired samples from areas only a few feet apart. The hay samples were harvested on September 9. The dodder was separated from the lespedeza and the samples of lespedeza dried in the shade. It was necessary to dry the dodder in an oven at 80° C to prevent additional growth and spoilage from the high moisture content. Oven-dry weights were obtained after the samples had reached a constant weight at 100° C.

The yields of hay are given in Table 1. The average yield of dodder-free lespedeza was 3,670 pounds and of the dodder–infested plots 3,677 pounds per acre. The amount of pure lespedeza was about 28% less on the dodder-infested plots than on the dodder-free plots, but the growth of dodder very nearly equaled the amount of the reduction of the lespedeza growth so that the total hay yields of both dodder-infested and dodder-free lespedeza were similar.

Table 1.—*Hay yields in pounds per acre of Korean lespedeza and dodder on a 12% moisture basis.*

Sample No.	Lespedeza grown with dodder			Lespedeza grown dodder free
	Lespedeza	Dodder	Lespedeza and dodder	
1	2,750	653	3,403	3,395
2	3,061	1,307	4,368	3,868
3	2,389	1,051	3,440	3,516
4	2,898	819	3,717	3,416
5	2,285	1,147	3,432	3,887
6	2,474	1,226	3,700	3,941
Average	2,643	1,034	3,677	3,670

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the North Carolina Department of Agriculture, and the North Carolina Agricultural Experiment Station. Received for publication October 14, 1940.

[2]Assistant Agronomist, Statesville, N. C.

Dodder-infested hay is readily eaten by livestock. As a measure of feeding value, chemical analyses of the samples were obtained and are given in Table 2 with grade determinations and leafiness. Many of the leaves on the dodder-infested lespedeza had yellowed and some had been lost before harvest, which accounts for the difference in grade between the two hays. These same factors probably also account for the lower protein and nitrogen-free extract and higher crude fiber content of the dodder-infested lespedeza as compared to that grown free of dodder.

TABLE 2.—*Chemical analyses of Korean lespedeza and dodder on a 12% moisture basis.**

Nature of sample	Class and grade	Protein %	Crude fat %	Crude fiber %	Ash %	Nitrogen-free extract %
1. Lespedeza grown dodder-free	U. S. No. 1, extra leafy, extra green lespedeza, 60% leaves	14.70	1.23	29.73	4.41	37.93
2. Lespedeza grown with dodder	U. S. sample grade, green, extra leafy, lespedeza, foreign material, 28.12% dodder	12.35†	1.37†	28.26†	4.53†	41.49†
3. Lespedeza with dodder removed‡	U. S. No. 1, extra leafy lespedeza, 55% leaves	12.01	1.29	33.40	4.59	36.71
4. Dodder removed from the lespedeza of sample 3		13.23	1.57	15.08	4.39	53.73

*Analyses and grade determinations by Grain and Seed Division, Agricultural Marketing Service, U. S. Dept. of Agriculture.
†Calculated from analyses of the dodder and lespedeza made separately, items 3 and 4.
‡Pure lespedeza from which dodder of sample 4 had previously been separated.

The dodder contained slightly more protein than the lespedeza upon which it grew but less than the lespedeza grown dodder-free. The crude fiber content of the dodder was about half that of the lespedeza. Combining the analyses of the lespedeza and the dodder that grew on it, we have a hay slightly lower in protein and crude fiber and higher in fat, ash, and nitrogen-free extract than the hay grown dodder-free.

Square yard samples from the same field were harvested on October 23, 1939, for seed yield determinations. Ten samples were obtained from the dodder-infested areas and a like number in the dodder-free lespedeza. The seed yields are given in Table 3. The average seed yield of the lespedeza grown dodder-free was 712 pounds while the infested lespedeza seed yield was 70% less. The dodder produced an average of 390 pounds of seed per acre.

TABLE 3.—*Seed yields in pounds per acre of Korean lespedeza and dodder computed from square yard plots.*

Sample No.	Lespedeza grown dodder-free	Lespedeza and dodder grown together		
		Lespedeza	Dodder	Total of lespedeza and dodder
1	736	133	487	620
2	759	260	297	557
3	695	273	300	573
4	712	284	380	664
5	796	85	450	535
6	842	247	460	707
7	633	215	377	592
8	617	199	284	483
9	653	170	471	641
10	678	251	394	645
Average	712	212	390	602

SUMMARY

1. Under the conditions of an experiment conducted during 1939 at Statesville, North Carolina, hay made from dodder-infested lespedeza contained 72% lespedeza and 28% dodder.

2. The total hay yield from the dodder-infested plots was similar to the yield from the dodder-free plots.

3. There was some loss of leaves and considerable loss in color of the dodder-infested lespedeza.

4. The protein content of the dodder was slightly greater than that of the lespedeza on which it was grown but was somewhat less than that of lespedeza grown free of dodder.

5. Dodder contained only about half the amount of crude fiber found in the lespedeza.

6. Seed yields of the Korean lespedeza were reduced from 712 to 212 pounds per acre by the dodder.

NOTES

STORING ALFALFA SEEDLINGS[1]

A RECENT experiment has shown that alfalfa seedlings may be stored for at least five months without material loss of plants. Storing seedlings for such a period makes it possible to grow two crops in the same greenhouse space through the winter for spring transplanting.

The experiment was conducted by placing a definite number of plants in each of a series of commercial cold storage rooms at temperatures ranging from 42° F to as low as 18° F. The plants used were from a field seeded the previous fall with certified Kansas Common seed. The seedling roots when dug in June averaged about 8 mm in diameter. Before storing, the roots were washed, the tips cut off 8 inches below the crown, and the tops trimmed, leaving very little green material. These plants were hardened slightly by first placing them in a temperature of 50° F for 3 days and then in lower temperatures as reported in Table 1.

TABLE 1.—*Percentage survival of alfalfa plants after a period in cold storage.*

Length of storage period, months	Percentage survival at a temperature of		
	40° to 42° F	32° to 34° F	14° to 18° F
1	100	100	0
2	100	100	0
3	100	100	0
4	80	96	0
5	92	96	0

Every 30 days for 5 months 50 plants were removed from each room and planted in the greenhouse to determine the survival. They were left in the bed long enough to be certain of their survival.

Actual experience in 1940 corroborated the results of the experiment. During the winter of 1939–40, 25,000 seedlings were grown in the greenhouse. Half of these, from seed sown in September, were placed in a cold storage room in January at 34° to 38° F without hardening, and transplanted to the field in May. A similar number, from seed sown in the greenhouse in January, was transplanted directly from the greenhouse beds to the field in May. Very few plants were lost from either group; no more than would normally be expected in transplanting.

The response of the two groups after transplanting was striking in that the stored plants started growth quicker and were in bloom four to five days earlier than those transplanted directly from the greenhouse.—C. O. GRANDFIELD, *Kansas State College, Manhattan, Kansas.*

[1]Joint contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and the Agronomy Department, Kansas Agricultural Experiment Station, Manhattan, Kansas. Contribution No. 311 Department of Agronomy.

A SUGAR BEET SAMPLE WASHER

A NEW type of sugar beet sample washer has been developed at the Michigan State Experiment Station. This washer (Fig. 1) consists essentially of a tank, approximately 36 by 34 inches and 30 inches deep, and a rotating skeleton drum containing the cages or baskets in which the samples of roots are placed. The skeleton drum, mounted

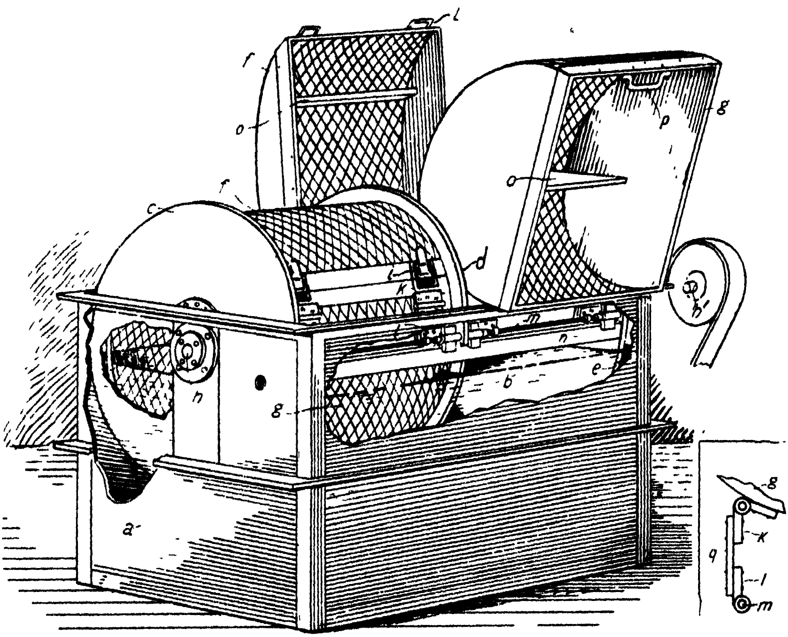

FIG. 1.—New type sugar beet sample washer.

on short shafts at either end, consists of parallel disks, approximately 30 inches in diameter, with three cross bars attached to them at the circumference. One of these cross bars is shown (n); the others are at the succeeding 90 degree points on the circumference so that a full 180 degrees is left without any cross bar.

A special feature of this machine is the construction of the cages. Each consists of a top and a bottom section. When the rotating drum is stopped at the proper point, the top section, hinged to the back cross bar, can be turned back out of the way and the bottom section, double hinged (see inset) to the front cross bar, can be turned up and forward to a position where the washed roots will fall out.

With this machine the roots are washed in water that is stirred gently by the baffles on the inside of the cages (the drum and cages revolve from 15 to 20 times a minute), and the thoroughness of the washing is determined by the length of time the sample remains in

the machine. Since the beet roots are in water all the time they are being washed, root breakage is reduced to a minimum.

Further information concerning the construction of this machine will be furnished anyone interested.—J. G. LILL, *Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, East Lansing, Michigan.*

BURIED RED RICE SEED[1]

WE HAVE previously[2] reported on the vitality of two varieties of commonly cultivated rice and of five lots of red rice after being buried in the soil for seven years. Both the Supreme Blue Rose rice and the Caloro rice failed to survive the second winter in the ground. After the seventh winter, practically all of the red rices were dead at Biggs, Calif., and Beaumont, Tex. At Stuttgart, Ark., both the Southern Blackhull rice and the two southern red rices were still alive. In the spring of 1940, the last remaining lot of seed was taken up at Stuttgart and gave the germination shown in Table 1.

TABLE 1.—*Vitality of red rice after being buried in the soil at Stuttgart, Ark., for 10 years.*

Kind	Percentage germination	
	Irrigated soil	Non-irrigated soil
Southern red	9.0	0.0
Southern red	21.0	0.0
Southern Blackhull	28.0	0.0
Italian red	0.5	0.5

It is interesting to note the persistence in the irrigated plot as compared with the non-irrigated plot.—W. L. GOSS AND EDGAR BROWN, *U. S. Dept. of Agriculture.*

[1]Contribution from the Grain and Seed Division, Agricultural Marketing Service, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[2]Jour. Amer. Soc. Agron., 31:633–637. 1939.

BOOK REVIEWS

HANDBOOK OF MATHEMATICAL TABLES AND FORMULAS

By Richard S. Burington. Sandusky, Ohio: Handbook Publishers, Inc. Ed. 2. VI+275 pages. Illus. 1940.

THE contents of this volume, except for slight additions, forms an appendix to Lange's Handbook of Chemistry. An examination of either the first or third edition of the latter will acquaint the worker with the contents of the mathematical handbook. The additions consist of over 100 equations in the table of Integrals, tables of Logarithms of Factorial n, Factorials and Their Reciprocals, and Binomial Coefficients. The table of Squares, Cubes, etc., has been increased by the addition of values for Square Root on $10n$, Cube Root of $10n$, and Cube Root of $100n$.

The first part of the volume (95 pages) consists of "formulas and theorems from elementary mathematics" which include algebra, geometry, trigonometry, analytical geometry, differential and integral calculus, and vector analysis. Many research workers would consider part of the discussion and many of the formulas as being more than elementary. The second part (173 pages) consists of 30 tables such as four, five, and seven place common logarithms of numbers, natural logs of numbers, natural trigonometric functions and logarithms of the same, exponential and hyperbolic functions, tables of radian measure (4), circular measure (2), gamma function, factorials, probability functions, factors for probable error, interest, discount, annuity, American mortality, etc. An index completes the volume.

This work, while giving numerous, extensive tables of use to engineers, physists, chemists, and other scientists, omits many tables of value to the statistician and biometricians (probably because of copyright restrictions) so should be considered as supplementary to such works as Pearson's Tables and those of other statistical workers. Neither is the table of Squares, Cubes, etc., as extensive as the well-known Barlow's Tables. Even with these omissions, the author has packed an immense amount of mathematics in a small volume. In fact the very brevity of most mathematical handbooks is a serious defect in the eyes of many workers including research scientists. Mathematicians can scarcely realize how "rusty in math" most workers become within a few years after leaving college. Illustrative examples worked out with sufficient detail to show how the complicated formulas of higher mathematics should be computed and how some of the less common tables should be used would be greatly appreciated by many workers. More mensuration formulas would also be welcomed.

The book is well written, and the paper, printing, and binding are excellent. Placing the mathematical part in a separate volume is an advantage to those not interested especially in the Chemical Handbook since it makes a less expensive volume and one more convenient for computing. (F. Z. H.)

AN AGRICULTURAL TESTAMENT

By Sir Albert Howard. London: Oxford University Press. 253 pages, illus. 1940.

THE major thesis of the author of this book is that the loss in soil fertility resulting from the vast increase in crop and animal production in order to feed the growing population of the world, has led to disastrous consequences. The result has been a general unbalancing of farming practices, an increase in plant and animal diseases, and finally the actual removal of soil by erosion. These losses can be overcome only by proper addition of humus or humus-forming materials to the soil and by the utilization of the activities of mycorrhiza fungi, which form the living bridge between soil humus and plant growth.

Sir Howard has written a most stimulating book and, although some readers may not fully agree with his general thesis, they will not lay this book aside until they have read it through. (S.A.W.)

STATISTICAL METHODS

By George W. Snedecor. Ames, Ia.: The Iowa State College Press. Ed. 3. XIII + 422 pages, illus. 1940. $3.75.

QUOTING the publisher, this "third edition was published under the imprint of the Iowa State College Press, whereas former editions were published by the Collegiate Press, Inc. This amounts principally to a change in name (of publisher), but it also brings to the book and future books published under the new imprint the approval of an editorial board drawn from the staff of Iowa State College".

With the exception of corrections of errors and additions mentioned below, the text of the second edition is practically unchanged, although section 10.16 has been largely re-written. The reader is referred to previous reviews in this JOURNAL, as follows: Original edition, Vol. 29, page 1033; second edition, Vol. 30, page 1045.

The total additions embrace 34 pages and, in addition to the entire last chapter, include the following sections: (1) Analysis of variance in regression; and (2) transformation of data for tests of significance in which square root, angle, and logarithmic transformations are discussed. The complete table of angle-arcsine $\sqrt{\text{percentage}}$ by Bliss is also included which is fortunate since many students might not have access to the Russian journal in which this table appeared originally.

The largest addition is Chapter 17 (29 pages) entitled "Design and Analysis of Samplings". Here the author points out the pitfalls to be avoided in sampling and gives numerous worked examples of analysis of such data. The headings of this chapter are population, sampling from a homogeneous population, size of sample, sampling from small populations, sampling from two or more homogeneous populations, analysis of data from two or more populations, structure of sampling investigations, and the effectiveness of subdivision. All these additions should be welcomed by workers in agriculture and biology for whom this volume is especially designed. (F. Z. H.)

SOIL PHYSICS

By L. D. Baver. New York: John Wiley & Sons. IX+370 pages, illus. 1940. $4.

THERE has been rapidly developing in recent years an increasing tendency to differentiate more and more clearly the various phases of the field of agronomy. The subject matter dealing with the physical properties of soils has generally been covered more or less completely in text books of agronomy or soils. Ever since the classic work of King and later Hilgard the importance of the physical aspects of soils has been recognized. In later years as the subject developed soil workers and teachers have felt the need of something really comprehensive dealing with these physical properties. A great deal of research has been done in the field but, as the author of the present volume points out, this material is scattered widely with a large part of it in foreign publications. This is one reason why Keen's "The Physical Properties of the Soil", published in 1931, was well received.

"Soil Physics" has been prepared, according to the author, to meet these needs, especially of the teacher of soils as the material is stated to be of graduate and advanced undergraduate grade. The author is one who has apparently felt this need in his own teaching work and furthermore is well qualified both in teaching experience and in soil research.

The book covers mechanical composition, soil colloids, soil consistency and structure, water, air, heat, and physical properties as related to tillage, runoff, and erosion. The more fundamental references are given at the chapter ends and the book has an author and subject index. It should be warmly welcomed by teachers of the subject of soils and by research workers in the same field. (R. C. C.)

MINUTES OF THE THIRTY-THIRD ANNUAL MEETING OF THE AMERICAN SOCIETY OF AGRONOMY

THE thirty-third annual meeting of the Society was held in the Drake Hotel in Chicago, Illinois, December 4, 5, and 6. There were 667 registered at the meetings which were held jointly with the Soil Science Society of America.

The general meeting of the Society was held on Thursday morning, December 5, with President F. J. Alway presiding. Dr. E. J. Krauss of the University of Chicago gave a very interesting illustrated lecture on "Possible Use of Growth Substances in Agricultural Practice". This was followed by a paper entitled "Integrating Soils and Crops Research" by R. M. Salter, Director of the North Carolina Agricultural Experiment Station. Both papers were very well received by the members in attendance and will be published in the JOURNAL.

The annual dinner of the Society was held on Thursday evening. Following the dinner President F. J. Alway gave an address on "A Nutrient Element Slighted in Agricultural Research".

The Crops Section had one general session and nine subsectional meetings at which 51 papers were presented. In addition, there were two round table discussions.

The Soil Science Society of America had one general program and 13 sectional programs with a total of 74 papers.

A joint meeting of the Soils and Crops Sections was held on Wednesday afternoon at which time six papers were presented in a symposium on "Relation of Soil Types and Fertilizer Treatment to Quality and Composition of Crops".

"War and Agricultural Adjustment with Special Reference to Grassland Agriculture" was the subject for discussion on a joint program Friday afternoon.

The Auditing Committee appointed by President Alway consisted of Dr. F. B. Smith and Dr. L. A. Richards. The Nominating Committee consisted of President Alway, chairman, and Dr. W. H. Pierre, Dr. S. C. Salmon, Dr. W. B. Kemp, and Dr. F. C. Bauer.

FELLOWS ELECT

VICE President L. E. Kirk announced the Fellows Elect and presented the certificates at the annual dinner on the evening of December 5. The following were elected Fellows of the Society: Dr. L. F. Graber, Dr. P. C. Mangelsdorf, Dr. F. W. Parker, and H. R. Smalley. The citations of these Fellows will appear in a later number of the JOURNAL.

OFFICERS' REPORTS

REPORT OF THE EDITOR

ONCE more the time has come to take stock of another volume of the JOURNAL. Volume 32 for 1940 will not differ materially from the last few preceding volumes, at least with respect to number of pages, number of articles published, and so on. This has become a rather routine record, but here are the figures

for 1940: Papers published, 109; "Notes" published, 17; book reviews published, 13; papers now under review, 11; papers approved and awaiting publication, 12; papers returned for one reason or another, 17.

The JOURNAL is really in very good shape with respect to manuscripts. The January 1941 number is now in the hands of the printer and there are sufficient papers in sight for the February issue without drawing on manuscripts that will be forthcoming from this meeting. This means that publication in the JOURNAL may be reasonably expected within a three months' period after acceptance of a paper, and this is just a comfortable margin from the standpoint of the Editor.

Here is the usual procedure A manuscript is received in our office on December 4, let us say. Generally, the day the manuscript arrives it is entered on our record and a post card acknowledging receipt is mailed to the author. At the same time the manuscript is transmitted either to the Associate Editor in Crops or the Associate Editor in Soils, depending upon the subject matter.

While there is a good deal of variation in the length of time that papers are in the hands of the reviewers, generally we have a report on the manuscript within two weeks, or for purposes of our illustration, we would expect to have a report on a paper received on December 4 about December 18. Almost invariably, the report from the reviewers will necessitate a letter to the author and generally will call for return of the manuscript itself for further attention. If you submit a manuscript to the JOURNAL and skip this step in the procedure, you may count yourself as among the favored few who tell their story so clearly the first time that even the reviewers can understand what it is all about.

But if you are one of the great majority of contributors to the JOURNAL, you will be given an opportunity to benefit from the suggestions offered by the editorial board, and almost invariably you will welcome this opportunity. In my experience of 12 years of editing the JOURNAL, I have only encountered one instance in which a contributor resented even the implication that his paper could be in the least improved and demanded that it be published as submitted or not at all. It has not yet been published in our JOURNAL.

We do not expect that you are going to agree in all respects with the criticisms offered by the reviewers, but from our past experience we know that 99.9 per cent of you are going to welcome the opportunity to preview the line of attack that may be leveled against your paper should it be published without regard to the critical comments offered by a fair-minded group of reviewers.

The paper is in your hands and the next move is up to you and perhaps you will be surprised to know that most of the delay in moving a manuscript along in the publication schedule is right at this point due to the difficulty of getting papers back from the author. Of course if your paper came back on December 19 or 20, you would be too busy with your Christmas shopping to do anything about it until after Christmas and perhaps you will go off to the A. A. A. S. meetings or some other interruptions will occur during the Christmas holidays so that it will be well along into January before you dig down through the accumulations on your desk and set to work to make such revisions of your manuscript in the light of the reviewers' comments as you may deem desirable.

At best you will not get your paper back to us until about the middle of January, long after the copy for the February number of the JOURNAL has had to go to the printer. And so the best that we can do with this theoretical paper which reached us on December 4 is to edit it for the March number of the JOURNAL, hence publication within three months after submission of a manuscript is about as early as one may reasonably expect under our present procedure.

This is the reason, too, why we need a "back log" of papers to insure a steady flow of manuscripts to the printer.

Order of publication in the JOURNAL is by priority, that is the papers appear in the order of their date of receipt in our office, insofar as circumstances will permit. Undue delay in acting on a manuscript by the reviewers or by the author will, of course, throw a paper out of line. For example, a paper now scheduled for the February number of the JOURNAL was actually received on July 8 but was returned to me by the author only a few days ago.

All of this is to say again that the JOURNAL is now in a position where it can render reasonably prompt service and we would welcome the opportunity to see just as many papers as you wish to send our way.

The inauguration at the last annual meeting of an Editorial Board comprising two Associate Editors and a corps of Consulting Editors has, in our estimation, proved to be one of the most constructive moves and certainly the most helpful action so far as the Editor is concerned, that has transpired for some time. The two groups of Consulting Editors, headed up by Dr. R. J. Garber for crops and Dr. Emil Truog for soils, have taken their responsibilities seriously and have rendered a truly important service to the Society and the JOURNAL. They and a number of others whom they have called upon from time to time to aid them in dealing with manuscripts of a highly specialized character are deserving of the gratitude of all of us for maintaining the high standards that we like to believe characterize the JOURNAL.

One thing more about manuscripts. One of the Associate Editors wrote to us last summer as follows: "I think we will have to try and do something in the way of educating some of our members in the matter of writing articles which are suitable for publication. If the authors would spend a little more time in studying their article and polishing it up, it would certainly help a lot in lessening the work of the reviewer and also in hastening the time of publication. . . . The reason it now takes such a long time to get the articles reviewed and finally approved is because of the unsatisfactory shape in which the articles are submitted." I am sure a great chorus of "Amens" to that statement would go up from editors of scientific journals in general.

We do not expect literary masterpieces; but it is a fact that much could be done in the way of better organization and in more accurate grammatical construction of papers coming to the JOURNAL. As an aid in this direction we are appending to this report a "Guide to Contributors to the JOURNAL". This will aid in the organization of a manuscript along the lines recognized as the style of the JOURNAL. This does not mean that our style is the one and only way of doing things, but it is recognition on the part of all, we assume, that there should be some consistent procedure in editorial details and general appearance of the JOURNAL. A little observation on the part of contributors of the printed pages of the JOURNAL and use of this "Guide" should go a long way toward meeting the needs expressed above.

During the year, we have entered into an agreement with a firm of advertising solicitors who, beginning January 1 next, will assume full responsibility for the advertising in the JOURNAL. This plan already shows promise of substantial gains in advertising revenue in 1941 and is recognition of the fact, of which we have long been aware, that personal contact with potential advertisers would accomplish much more than a letter-writing campaign to which of necessity we have been largely confined in the past. We have enjoyed a fairly good year in

the way of advertising and wish here to acknowledge our thanks to those advertisers who have patronized the JOURNAL during 1940.

For purposes of the record, we would report here the number of copies of the various agronomic publications entrusted to our care which have been shipped out since January 1. They are as follows: 7 sets of the PROCEEDINGS of the First International Society of Soil Science; 13 BULLETINS of the Soil Survey Association; 40 INDEXES to the JOURNAL; 1,892 back numbers of the JOURNAL; 132 volumes of PROCEEDINGS of the Soil Science Society; and 4 sets of the TRANSACTIONS of the Third Commission of the International Society of Soil Science.

We still need to be kept better informed on matters of general agronomic interest to be published under the heading of "News Items". Some of our correspondents are very regular; but for the most part such news items as we do gather together are come upon in a very haphazard manner. We suggest that all of you make "more news for the JOURNAL" one of your 1941 New Year's resolutions.

Once again in concluding another report and another volume of the JOURNAL we acknowledge the invaluable aid and cooperation of the Secretary. His patience and good nature must be unfailing, for I am sure we try them mightily throughout the year. The smooth functioning of his office is essential not only to the efficient conduct of the affairs of the Society, but to the maintenance and publication of the JOURNAL as well. That both are flourishing is concrete evidence of his efficiency.

Respectfully submitted,

J. D. LUCKETT, *Editor.*

REPORT OF THE SECRETARY

THE membership changes in the Society since the last annual report are briefly summarized as follows:

Membership last report		1,205
New members, 1940	127	
Reinstated members	67	
Total increase	194	
Dropped for non-payment of dues	187	
Resigned	18	
Died	6	
Mail returned unclaimed	12	
Total decrease	223	
Net decrease		29
Membership, October 31, 1940		1,176

The changes in number of subscribers are as follows:

Subscriptions, last report		687
New subscriptions, 1940	89	
Subscriptions dropped	182	
Net decrease		93
Subscriptions, October 31, 1940		594

The paid up membership and subscription lists by states and countries are as follows:

	Members	Subscriptions
Alabama	17	1
Arizona	12	5
Arkansas	16	4
California	49	14
Colorado	20	1
Connecticut	11	2
Delaware	4	1
District of Columbia	91	6
Florida	18	3
Georgia	20	6
Idaho	9	1
Illinois	56	13
Indiana	30	4
Iowa	42	4
Kansas	46	4
Kentucky	11	3
Louisiana	18	5
Maine	5	1
Maryland	15	4
Massachusetts	13	4
Michigan	23	5
Minnesota	32	5
Mississippi	12	3
Missouri	21	3
Montana	9	6
Nebraska	36	4
Nevada	3	1
New Hampshire	2	1
New Jersey	19	4
New Mexico	5	3
New York	44	15
North Carolina	20	6
North Dakota	12	1
Ohio	53	5
Oklahoma	13	5
Oregon	12	4
Pennsylvania	22	7
Rhode Island	7	0
South Carolina	19	2
South Dakota	8	1
Tennessee	14	3
Texas	52	14
Utah	15	6
Vermont	3	1
Virginia	26	3
Washington	24	4
West Virginia	10	1
Wisconsin	35	4
Wyoming	7	1
Alaska	1	1
Hawaii	6	12
Philippine Islands	1	2
Puerto Rico	4	3

	Members	Subscriptions
Africa	4	27
Argentina	10	15
Australia	1	28
Belgium	0	1
Brazil	1	9
British Guiana	0	1
British West Indies	1	1
Bulgaria	0	1
Canada	25	42
Ceylon	0	3
Chile	1	1
China	5	17
Colombia	0	2
Cuba	4	2
Denmark	2	1
Dutch East Indies	0	5
Egypt	0	3
England	2	15
Estonia	0	1
Fed. Malay States	0	5
Fiji	0	1
Finland	0	6
France	0	7
Germany	4	3
Greece	0	2
Holland	0	5
Honduras	0	2
India	4	25
Indochina	0	1
Ireland	0	1
Italy	1	7
Japan	2	82
Mauritius	0	1
Mesopotamia	0	1
Mexico	1	2
New Zealand	0	6
Norway	0	2
Palestine	2	0
Peru	0	3
Portugal	0	5
Roumania	0	1
Scotland	2	2
Siam	2	2
Spain	0	2
Sweden	0	3
Switzerland	1	1
Turkey	2	1
Uruguay	1	0
Russia	1	9
Venezuela	1	2
Wales	0	3
Total	1,153	590

The total membership shows 29 members less than were reported last year. This is explained by the larger number of members who were dropped for non-payment of dues. On July 1, all members who had not paid their 1940 dues or who had not indicated that they would pay later were dropped from the membership

rolls. As a result we have only 23 members on our rolls who have not paid 1940 dues. At the time of last year's report there were 179 members who were at least one year behind in payment of dues. Thus, although our total membership is lower than last year, we have 126 more paid up members than we had one year ago. This increase in members in good standing is in part the result of more prompt payment of dues and also the increased number of new members. The cooperation of the various state representatives, as well as other members of the Society, has made this possible.

The total number of subscribers is 93 less than last reported. The large decrease is principally due to the fewer number of subscribers in the U. S. S. R. Last year there were 95 Russian subscribers, whereas this year there are only 9, a decrease of 86. The number of paid up subscribers is only 8 less than last year. Under present conditions it seems doubtful if we can hope to increase the number of subscribers outside the United States. However, the increase in paid subscribers in this country during the past year has been very gratifying. It is hoped that the Society can continue to make up for losses of foreign subscriptions by the increase in our own country.

The policy of dropping members and subscribers for non-payment after six months delinquency has undoubtedly helped to speed up payment of dues and subscriptions. Before any members were dropped from the rolls they were sent three notices of dues, two of which asked them to reply if they were unable to send in their remittance at that time. If no reply was received from any of these notices, the members were dropped July 1. The same policy was applied to subscribers. This is a very lenient policy as compared to other scientific societies. It is hoped that the date for dropping delinquent members and subscribers can be further advanced during the coming year.

The Secretary appreciates the fine cooperation which the members have given during the past year. The valuable aid of state representatives in securing new members and the prompt and efficient work of the program chairmen deserve particular mention.

Respectfully submitted,

G. G. POHLMAN, *Secretary.*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year, November 1, 1939 to October 31, 1940.

RECEIPTS

Miscellaneous	$ 29.00
Convention receipts	1,087.00
Advertising income	882.46
Reprints sold	1,377.33
Journals sold	167.31
Subscriptions, 1939	334.16
Subscriptions, 1940	2,279.20
Subscriptions, 1940 (new)	448.69
Subscriptions, 1941 (advanced)	208.23
Dues, 1939	555.59
Dues, 1940	4,795.26
Dues, 1940 (new)	605.17
Dues, 1941 (advanced)	59.00
Index	46.70
Miscellaneous (S.S.S.A.)	368.80

Sale of Soil Survey Bulletins (Marbut Memorial Fund)	$ 87.60
Sales of Proceedings, Vol. I (1936)	199.46
Sale of Proceedings, Vol. II (1937)	155.45
Sale of Proceedings, Vol. III (1938)	406.63
Dues and Subscriptions S.S.S.A. 1940	2,388.17
Dues and Subscriptions S.S.S.A. 1940 (new)	288.50
Dues and Subscriptions S.S.S.A. 1941	28.00
Membership only, S.S.S.A., 1940	27.00
Sales of I.S.S.S. Proceedings and Transactions	144.38
Fees, I.S.S.S., 1939	55.00
Fees, I.S.S.S., 1940	706.30
Fees, I.S.S.S., 1940 (new)	57.00
Total receipts	$17,787.39
Balance in cash, November 1, 1939	1,973.14
Total income	$19,760.53

DISBURSEMENTS

Printing the Journal, cuts, etc		$ 8,060.08
Salary of Business Manager and Editor		735.00
Postage, Business Manager and Secretary		131.44
Printing, miscellaneous		165.60
Express		13.12
Mailing clerk and stenographer		1,263.07
Refunds, checks returned, etc		99.04
Expenses for meetings		1,238.13
Miscellaneous		191.18
S.S.S.A. expenses, printing proceedings, etc		4,248.85
I.S.S.A. expenses, fees to Dr. Hissink, etc		928.79
Total disbursements		$17,074.30
Total income	$19,760.53	
Less total disbursements	17,074.30	
Balance in checking account October 31, 1940	$ 2,868.23	
Balance in trust certificate	267.71	
Balance in savings bonds	2,340.00	
Total assets		$ 5,293.94

Respectfully submitted,
G. G. POHLMAN, *Treasurer.*

REPORT OF THE AUDITING COMMITTEE

THE Committee have examined the books of the Treasurer and find the accounts correct as reported.

L. A. RICHARDS
F. B. SMITH, *Chairman*

OTHER COMMITTEE REPORTS

BIBLIOGRAPHY OF FIELD EXPERIMENTS

THE committee has compiled a bibliography of 45 titles of the more important contributions on the methodology of and interpretation of results of field plot experiments, either reported since or not included in the revised bibliography published in the JOURNAL (Vol. 25: 811–828, 1933; and the additions in Vol. 27: 1013–1018, 1935; Vol. 28: 1028–1031, 1936; Vol. 29: 1042–1045, 1937; Vol. 30: 1054–1056, 1938; Vol. 31: 1049–1052, 1939).

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F. R. IMMER
H. M. TYSDAL
H. M. STEECE, *Chairman*

PASTURE IMPROVEMENT

GRASSLAND CONFERENCES

FOR the past few years the primary study of the Committee on Pasture Improvement of the American Society of Agronomy has been the relative value of various crops used as pasturage, hay, silage, or grain when grown under comparable soil and climatic conditions. In America's trend toward a grassland agriculture it is evident, and essential, that greater consideration be given to the productivity of various forage and pasture crops as compared to other harvested feed crops, and to the relative differences in composition and feeding value. Greater consideration of these and related problems was brought about by encouraging and assisting with a series of five special "Grassland Research Conferences" usually in conjunction with other meetings, especially the summer meetings of the American Society of Agronomy. Such conferences are particularly successful in the summer when the specialists have an opportunity to examine and study the investigational work under way in the various sections of the country.

When arrangements were under way for these Regional Technical Grassland Conferences, the question was repeatedly asked as to when the public was to

be taken into our confidence as to our objectives, procedures, progress to date, research needs, etc. The Pasture Improvement Committee considered the desirability of the group, sponsoring, or assisting regional groups with general meetings to which the public would be invited, these general meetings to be held for one or two days immediately following the technical conferences. By the public we had in mind state and federal workers and the agricultural leaders in the region —that is, leaders of farm organizations, outstanding farmers, ranchers, county agents, action agencies, industries, railways, etc. Two types of regional conferences were considered—first, informal conferences of technical workers directly concerned with pasture and grass investigations, and second, a general conference open to the public at which agricultural leaders in the region would be asked to participate.

In order to bring about a coordinated approach to the organization of the conferences in the several Bureaus of the U. S. Department of Agriculture, the Secretary of Agriculture appointed a Departmental Committee to work with and assist local committees in each region. The Head Agronomist in Charge of the Division of Forage Crops and Diseases in the Bureau of Plant Industry was appointed chairman of the Departmental Committee. The Northeastern Committee was headed by Dean S. W. Fletcher; the Southeastern by Director S. H. Starr; the Western by Director William Peterson; the Northcentral by Dean R. E. Buchanan, and the Southern Great Plains by Prof. R. I. Throckmorton and Dr. E. R. Henson.

The Regional Grassland Conference in the Northeastern Section of the country was held at State College, Pennsylvania, July 10–12. The Conference was officially sponsored by the Northeastern Section of the American Society of Agronomy and by the Pasture Improvement Committee of the Society. The program consisted of three general sessions: (1) "General Perspective", (2) "Adjustments in Farm Practices as Affected by Grassland Agriculture", and (3) "Educational Objectives of a Grassland Agriculture". Approximately 250 people attended this Conference. The collaborators of the U. S. Regional Pasture Research Laboratory had its annual technical conference just preceding the Grassland Conference and the Northeastern Section of the American Society of Agronomy had its annual summer meeting immediately following.

The Regional Grassland Conference in the West was held at Salt Lake City, Utah, July 15–17, and about 250 people came out to these meetings. The Conference was officially sponsored by the Pasture Improvement Committee of the American Society of Agronomy. The staff of the Range Research Division of the Forest Service took an active part in assisting with arrangements. The meeting was held immediately following the summer meeting of the Western Section of the American Society of Agronomy. The program was opened with a general discussion of "Grass in Western Agriculture", then followed six general sessions: (1) "Pastures", (2) "Grass on Range Lands", (3) "Grass as a National Resource", (4) "The Place of Grass in Soil and Water Conservation", (5) "Grassland Research", and (6) "Grass and the Public". The final day of the Conference was devoted to a tour of pasture and range areas.

The Regional Grassland Conference in the Southeastern Section of the country was held at the Georgia Coastal Plain Experiment Station, Tifton, Georgia, July 25–26. The Conference was officially sponsored by the Association of Southern Agricultural Workers and the Pasture Committee of the American Society of Agronomy. The program consisted of three general sessions, as follows: (1) "General Perspective", (2) "Economic and Social Impacts of a Grassland Agri-

culture", and (3) "How to Achieve a Grassland Agriculture Suitable to the South". The afternoon of the first day was devoted to nine group discussions on pertinent grassland problems. Each afternoon field excursions were organized to visit pasture and grass breeding plots on the Experiment Station. The meeting had an enthusiastic attendance of about 500 people. At the annual meeting of the Association of Southern Agricultural Workers in Birmingham last winter, a group of specialists interested in pasture and forage crop research organized the "Southern Pasture and Forage Crop Improvement Committee". This group sponsored a two-day technical conference just preceding the Southern Grassland Conference. The Pasture and Forage Crop Improvement Committee of the Association of Southern Agricultural Workers plans to sponsor a technical conference each year at one of the southern institutions.

The Southern Great Plains Regional Grassland Conference was held in Amarillo, Texas, September 5 and 6. The Conference was officially sponsored by the Southern Great Plains Agricultural Council, and was well attended by a group of about 350 interested guests. The Regional Coordinator's Office and the Soil Conservation Service assisted greatly with the organization of the Conference. The program was divided into four general sessions: (1) General perspective and problems involved, (2) Revegetation and grass improvement, (3) Economic and management problems, and (4) Panel discussion—"Forwarding a Grassland Agriculture". A five-day tour beginning at Woodward, Oklahoma, and passing through Southwestern Kansas, Southeastern Colorado, and ending at Amarillo, Texas, in time for the Grassland Conference, preceded the Conference.

The Northcentral Regional Grassland Conference was held at Ames, Iowa, September 11, attended by about 300 people. The Conference was officially sponsored by the Corn Belt Section of the American Society of Agronomy and the Association of Northcentral Experiment Station Directors, of which Dean W. C. Coffey of Minnesota is chairman. The program of four general sessions was as follows: (1) "The Use of Grass in Adjusting Production", (2) "Research Contributions and Needs", (3) "Education and Application", and (4) "Problems in Adjustment". The annual summer meeting of the Corn Belt Section of the American Society of Agronomy was held immediately preceding the Grassland Conference. The field demonstrations by the staff of the Iowa State College were directed toward the problems and possibilities of grassland development in the Corn Belt.

The Regional Grassland Conferences in the various sections of the country seemed to meet with much favor. In two regions invitations have already been extended by universities to continue the Conferences in some form next summer. A survey among those in attendance at these Conferences during the past year seemed to indicate that it would be desirable to have Regional Grassland Conferences at least once in 3 to 5 years, inviting the agricultural leaders to participate. More immediate needs, however, are Regional Conferences of technical workers to provide an opportunity to exchange ideas by way of informal discussion of methods and technics for carrying on grass and pasture research. Such a group, composed of collaborators of the U. S. Regional Pasture Research Laboratory at State College, Pennsylvania, has been formally organized in the Northeastern region. In the Southeast the Technical Conference will be sponsored annually by the Pasture and Forage Crop Improvement of the Association of Southern Agricultural Workers. In the Northcentral region a group has been meeting informally for a number of years with the summer meeting of the Corn Belt Section of the Agronomy Society. During the past summer this group gave

way to the general Grassland Conference held at Ames, Iowa. In the Mountain States technical conferences may be continued in the future in close association with the Range Management staff of the Forest Service, and in the Southern Great Plains, with the various agencies concerned with the revegetation and range problems common to the "Dust Bowl" and adjacent territory.

Many excellent papers were presented at the 1940 Regional Grassland Conferences and numerous inquiries and requests for copies have been received. A number have been mimeographed for preliminary distribution or publication in various trade and technical journals. Mr. Gove Hambidge, editor of the U. S. Department of Agriculture Yearbook, is considering the possibility of publishing these papers in the form of a Grassland Conference report or regional grassland pamphlets.

While the primary aim of the Regional Grassland Conferences is to bring together the technical workers such as agronomists, soil, range, dairy, livestock, nutritional, farm management, and economic specialists, leaders of farm organizations, extension workers, county agents, and specialists in agricultural departments of industries, railroads, and financial institutions, there is still the need to bring the grassland problems and methods for improvement to the attention of the farm and ranch operators. Several state institutions have proceeded to make arrangements for State Grassland Conferences. This is a desirable development and it is hoped that the local interests will proceed with such plans. Reports have also been received to the effect that a number of the institutions are making arrangements for "Grassland Days" at their annual Farm and Home Week. One of the industrial organizations has also formulated plans for local Grassland Research Conferences to bring to the attention of the specialists in this field the progress to date and future needs.

The program and activities of your Pasture Committee have been rather intensive during the past year, but the work has been facilitated by the cordial cooperation and support of the local institutions where the meetings were held, and by the many people throughout each region who presented papers and participated in the program. The publicity organizations too did a fine job of supporting the Conferences. Your Committee is very grateful indeed for all of this assistance.

DEVELOPMENT OF METHODS AND TECHNIC FOR GRASSLAND RESEARCH

Interests of specialists in soils and crops, range management, dairying, livestock production, nutrition, farm management, and botany and ecology have been sufficiently diverse to justify organizing separate professional groups or societies. Several of these organizations have recognized the importance of pastures by appointing standing committees to give special consideration to pasture problems. The development of improved methods and technics for measuring or evaluating pastures has been a problem common to all of these groups, and in recent years has received their special attention. Investigators concerned with such pasture research have compared notes and exchanged ideas. The need for coordination of efforts to develop uniform or improved technics has been apparent to the many workers who are attempting to measure or evaluate in some way the same or similar kinds of grasses and management practices.

A "Preliminary Presentation on Pasture Investigations and Technique", embodying the recommendations of the pasture committees of the American Society of Agronomy, American Dairy Science Association, and the American

Society of Animal Production, was issued as a report in 1935. In 1937 the Canadian Pasture and Hay Committee was added to the Inter-Society Committee.

It is now five years since the first report, "Preliminary Presentation on Pasture Investigations and Technique", was published. The Pasture Committee of the Dairy Science Association, at its annual meeting this year; did a thorough job of revision as far as their special interests are concerned. At the Regional Grassland Conferences held this summer emphasis was placed on the development of "methods" and many new and constructive suggestions were brought out and discussed. The collaborators' conference of the Northeastern States at the U. S. Regional Pasture Research Laboratory, devoted its entire meeting this year to methods of measuring and evaluating pasture experiments.

It is desirable that the valuable material developed at these conferences, and from other sources, be brought together in the contemplated revision of the report of the Joint Committee on Pasture Improvement. Committee members have urged the calling of a conference of the Joint Pasture Research Committee at Chicago this fall to consider the numerous suggestions and prepare a revised report and, accordingly, a meeting of the Joint Committee has been arranged for December 3, 1940, immediately following the annual meeting of the American Society of Animal Production and preceding the meeting of the American Society of Agronomy. This will be the first meeting of the Joint Committee since its organization in 1935.

The Inter-Society organization of the four mentioned Committees is known as the "Joint Committee on Pasture Research". It is recommended that the name of the "Joint Pasture Improvement Committee" of the American Society of Agronomy be changed to "Pasture Improvement Committee" of the American Society of Agronomy to avoid confusion when reference is made to the respective committees.

HENRY L. AHLGREN	ROBERT LUSH
B. A. BROWN	O. MCCONKEY
D. R. DODD	GEORGE STEWART
C. R. ENLOW	J. D. WARNER
R. D. LEWIS	O. S. AAMODT, *Chairman*

EXTENSION PARTICIPATION

WE ARE pleased to report a good attendance of Extension Agronomists at this meeting and we express our appreciation of the fact that the two Extension Agronomists have a place on the program.

Since the Extension Agronomist has a close contact with the farmer and knows what is going on in the field, he should be in a position to make valuable contributions to the programs of the Society. This viewpoint is often needed to round out properly the discussion of many problems.

We therefore recommend that the Chairman of the Committee on Extension Participation be made a member of the program committee.

J. C. LOWERY	E. L. WORTHEN
O. S. FISHER	E. R. JACKMAN
EARL JONES	L. L. COMPTON
	J. S. OWENS, *Chairman*

SOIL TILTH

THE Joint Committee on Soil Tilth, in their report to the 1939 meeting, attempted to call attention to the various physical properties of the soil that are implied in the term "soil tilth". Evidence was presented to indicate that the concept of tilth included certain structural properties of the soil that are exhibited within a given range of soil consistency. A short discussion of porosity and penetrometer methods for measuring tilth was included.

The Committee is no more prepared to offer a good definition of "tilth" than they were a year ago. The majority of the Committee, however, feel that the term as now used includes both of the following factors, *viz.*, workability and structural conditions favorable for plant growth. The suggestion is offered that some attempt be made to clarify the terminology so as to distinguish between these two concepts. This can only be possible after a careful solicitation of the views of various soil investigators.

Field and laboratory studies at the Ohio Agricultural Experiment Station during the past year have produced some encouraging preliminary results in the correlation of penetrometer and porosity data as expressions of soil tilth. A part of these results will appear in the 1940 volume of the Soil Science Society of America PROCEEDINGS. Further research is necessary to evaluate the importance of these measurements for characterizing tilth.

The Committee make the following recommendations for the coming year:

1. That an attempt be made to clarify the definition of soil tilth by enlisting the cooperation of interested soil investigators.
2. That the Committee should stimulate interest between soils men and agricultural engineers to cooperate on projects involving tilth problems. Such cooperation is now in progress at a few institutions.
3. That the Committee encourage more research on the importance of tilth in crop production.

J. F. LUTZ R. J. MUCKENHIRN
H. E. MIDDLETON L. D. BAVER, *Chairman*

STUDENT SECTIONS

THE following institutions have petitioned for charters in the Student Section of the American Society of Agronomy: Southwestern Louisiana Institute; University of North Carolina; and University of Georgia. The addition of these three chapters makes a total of 23 institutions with affiliated clubs.

During the past year the Society has prepared certificates of membership in the Student Section. These certificates are distributed free of charge to the members of the various chapters.

The essay contest topic was "Causes of Rundown Pastures and Methods of Their Improvement." The authors of the ten best papers were 1, John Lonnquist, University of Nebraska; 2, Milo B. Tesar, University of Nebraska; 3, Theodore H. Johnston, University of Nebraska; 4, Henry H. Hadley, University of Illinois; 5, Will Pitner, University of Nebraska; 6, Earl R. Leng, University of Illinois; 7, Andrew J. Andresen, University of Nebraska, and Richard L. Wood, University of Illinois (tie); 9, Lloyd C. Jones, Kansas State College; and 10, Robert L. Coolidge, Pennsylvania State College.

It is recommended that the abstracts of the three highest ranking papers be printed in the JOURNAL as a part of this report.

CAUSES OF THE RUNDOWN CONDITION OF THE WESTERN RANGE AND METHODS OF IMPROVEMENT

John Lonnquist, University of Nebraska

THE importance of the western range as a grazing region can be observed by the fact that 75% of the wool and mohair produced in this country comes from the western range and the total number of livestock in the area, according to the 1930 census, was over 63 million head valued at 1.4 billion dollars. From the period 1870 to 1920, this vast area was grazed with increasing intensity reaching a peak of 22.5 million animal units in 1920. After the war, livestock numbers declined rapidly until in 1934 the estimated carrying capacity was 10.5 million animal units. This tremendous reduction in carrying capacity resulted from faulty grazing practices and poor grazing management, which reduced the density of the vegetation of the area to about 52% of its virgin condition.

Overstocking has been the primary cause of range depletion. Premature grazing resulting from the stockmen's inability to provide sufficient winter feed for vast herds of stock has also been a serious factor in range depletion. The vegetation is eaten off before it has grown large enough to replenish the supply of organic root reserves used in renewal of growth in the spring. Thus, the vegetation becomes weakened and may be actually starved out. Burning has been used to bring about earlier growth of vegetation and consequently earlier range use, thus causing further damage from premature grazing. Lack of planned distribution of salting and watering places has had its effect on range depletion through excessive trampling and overgrazing around these areas when located too far apart.

Drouth decreases density of native vegetation, especially if prolonged for several years. Ranges adequately stocked during a normal season may become badly overstocked during a period of drouth unless the number of livestock is adjusted accordingly.

Erosion has resulted from decreased density of vegetation due to drouth and unwise grazing practices. It is, however, a factor in range deterioration as it destroys good land through gully formation and silting over of bottomlands.

Range improvement is concerned chiefly with the restoration and maintenance of the important forage species so that maximum production of forage is maintained from year to year.

Plant indicators are indispensable in determining whether ranges are being properly used or are being misused. Certain plants indicate a healthy range, while others may indicate various stages of range depletion.

Natural revegetation has been successfully accomplished by use of a deferred and rotational grazing system. The range is divided into three or four areas. One of these is then protected from grazing until seed has matured. The same area is again protected the following year until seedlings have become established. Each area receives the same 2-year treatment in a definite rotation.

Delaying grazing in the spring until the more important species have attained a height of 6 to 8 inches minimizes the damage from too early grazing. Ranges dominated by certain species may adapt themselves to seasonal grazing, depending upon the length of time the vegetation remains palatable.

Natural springs and seeps should be supplemented by construction of reservoirs located in such a manner that a wider utilization of the range is obtained. Proper distribution of salt away from watering places is of great help in attracting stock into unused areas.

Artificial reseeding as a means of restoration of range forage grasses has been successful only on areas where conditions were far above average. Where a few native species remain to furnish seed, natural revegetation, through deferred and rotational grazing, has been most satisfactory.

Moisture conservation and erosion control on the western range are possible only by maintenance of maximum density of vegetation.

CAUSES OF THE RUNDOWN CONDITION OF THE WESTERN RANGE AND METHODS OF IMPROVEMENT

Milo Benjamin Tesar, University of Nebraska

THE western range is an integral part of the nation's agriculture because it furnishes feed for over 11,000,000 animal units. Located west of the one-hundredth meridian, its 728,000,000 acres produce 75% of the wool and mohair, 55% of the sheep and lambs, and about 33% of the cattle produced in the entire United States.

This range area, which is one of America's greatest unrecognized resources, is today depleted to the extent of 52% of its virgin condition. It was once capable of carrying 22,500,000 animal units; today it carries only 10,800,000 units.

The three principal causes for the rundown condition of the western range are overgrazing, premature grazing, and continuous grazing. Most investigators are agreed that overgrazing is the main cause of the deterioration. It has reduced the ranges from 20 to 65% in grazing value. Closely related to overgrazing is premature grazing which depletes the stored root reserves of carbohydrates and decreases the quantity of forage and roots. Experiments by Aldous and others indicate that close continuous grazing reduces forage yields by about 25%, and that persistent grazing will eventually kill any established stand of grass.

Reports by various investigators show that a large percentage of the native grasses in the western range was killed by the drouth of 1934. This situation was aggravated further by the faulty distribution of livestock, a condition which resulted in uneven range utilization. Although other causes, such as burning, erosion, and rodent damage, have hastened the depletion of the range area, their effects would not have been serious if the range had been grazed conservatively.

The depleted condition of the range can be improved if proper methods are initiated. Such methods have been applied successfully in the national forests and the Sandhills of Nebraska where ranges are now in excellent condition.

The use of plant indicators as a guide to the intensity of range depletion is necessary. Range land that is moderately grazed may be reclaimed by the application of a deferred and rotational system of grazing. This consists of dividing the range into from two to five units and deferring grazing on a different unit each year until the seed crop has matured, thereby resting and grazing the units in rotation. Strategically located salting and watering stations on this range land will help materially in preventing undergrazing and overgrazing on the same area.

Those ranges that are eroded and are almost denuded of vegetation can be reclaimed only by reseeding with adapted species and by permitting the newly established vegetation to prevent further erosion. The use of native species in the Southwest and of adapted introduced species near the Dakotas and Montana is recommended.

Weeds and brush on a range should be eradicated by cutting or burning. Aldous states that most weeds can be destroyed by cutting annually during

the beginning-bloom stage at which time root reserves are lowest. A similar effort to control rodents by trapping, shooting, or poisoning should be started to insure the success of the range re-vegetation program.

CAUSES OF RUNDOWN PASTURES IN NORTHEASTERN UNITED STATES AND METHODS OF THEIR IMPROVEMENT

Theodore H. Johnston, University of Nebraska

MAJOR causes of rundown pastures in northeastern United States have been found to be low soil fertility, overgrazing, presence of undesirable plant species, poor stand of desirable species, erosion and improper drainage, and, to a lesser extent, burning. Low fertility of the soil is probably the chief cause in this area.

The type of pasture to improve is very important. Factors to consider include distance from farm buildings, accessibility to water, productivity of the land, available soil moisture, and several others.

Probably the most important method for improving pastures in this section is to increase the soil fertility. This can best be done by applying the necessary elements of fertility in proper amounts. Nearly all soils in this region have undergone excessive leaching, leaving them somewhat acid and therefore requiring lime. Phosphate fertilizers are needed on most soils in this section, while potash is needed to some extent. Available nitrogen is very essential for high yields of herbage and is supplied largely by the growing of legumes, especially white clover. If nitrogen is not supplied in sufficient quantities by legumes, then application of nitrate fertilizers is necessary. Manure has not been a very satisfactory source of nitrogen for pastures.

Certain plant species are much more desirable for pastures than others and the stands of such species can be improved by proper fertilization and re-seeding where necessary. White clover is probably the most important pasture legume, while several other clovers are grown to a considerable extent. Leading pasture grasses are Kentucky bluegrass, the bent grasses, redtop, orchard grass, and timothy. If new pastures are seeded, it is advisable to use a recommended pasture mixture. Various species differ in their adaptations and use of mixtures aids in establishing forage stands whatever the season.

Eradication or control of undesirable species can best be accomplished by increasing the growth of desirable species through proper fertilization and proper grazing. In this way most of the weeds are crowded out. Mowing weeds at the proper stage of development is likewise very effective.

The first essential practice in proper pasture management is prevention of too early grazing in the spring. Grazing should not be delayed too long, however, or much of the value of the herbage is lost.

Many of the pastures in this area are kept at a high level of production by following a system similar to the Hohenheim system of intensive pasture management. Under this method, heavy nitrogen fertilization and close, rotational grazing are practiced.

Supplementary pastures are needed during midsummer when permanent pastures are at a low level of production. Sudan grass has been found to be one of the best pasture crops for this period. Rye, millet, and meadow aftermaths may also be used.

Cultural practices which are deemed advisable include harrowing to scatter

droppings, use of a roller in spring if necessary, and mowing where grazing has been uneven. This mowing makes more uniform growth possible and helps to insure more uniform grazing.

G. H. DUNGAN M. B. STURGIS
A. L. FROLIK J. W. ZAHNLEY
J. B. PETERSON H. K. WILSON, *Chairman*

FERTILIZERS

Subcommittee on Soil Testing.—The results of 38 collaborators who have submitted their soil test results on the series of check soils assembled last year have been compiled and compared with reference to (1) effect of method on results obtained; (2) consistency of data of various individuals using the same methods; and (3) indications of the average results by soil tests with reference to the field records of crop production and response to treatment.

A comprehensive summary of these comparisons was presented before the general meeting of the Fertilizer Committee on December 3, and will appear in the mimeographed proceedings.

Further data on these soils with reference to laboratory determinations of exchangeable bases, available phosphorous and such other related chemical studies as may be made at various research laboratories will be compiled by the committee. Cooperation along these lines will be welcomed.

Correlations of soil test results and interpretations in terms of specific recommendations between soil testing agencies in regions of similar soils and cropping practices should be fostered by the distribution of samples of a few soils representing typical problems from several state soil testing laboratories, to others in their localities. It is suggested that this subcommittee serve as a clearing house for information obtained in such studies.

The special problem of phosphorous testing of soils of the semi-arid portions of the United States, especially those containing large amounts of carbonates, should be given increased attention. None of the present methods giving useful results in the humid region are likely to prove applicable to such conditions, although they are now being used in some instances. Research along this line will be encouraged by the committee.

The Committee sponsored the presentation of a program of your papers before the general meeting of the Fertilizer Committee.

M. F. MORGAN, *Chairman*

Subcommittee on Fertilizer Grades.—The Committee has continued its efforts toward (1) reduction of the number of grades recommended for use and offered for sale within a given state, (2) more unity in recommendation in adjoining states, and (3) making adjustments between lists of recommended grades and lists of grades offered for sale. The fertilizer industry has shown a willingness to cooperate in the reduction of the number of grades offered for sale and in harmonizing the list of grades offered with the list of recommended grades. This cooperation is greatly appreciated by the Committee and by agronomists.

Through the cooperation of the National Fertilizer Association an article prepared by D. D. Long, of this Committee, entitled "Reducing the Number of Fertilizer Analyses", was published in the August issue of *The American Fertilizer.* In this article the cost to manufacturers of producing a large number of grades is stressed.

In six states the number of grades offered for sale is limited to grades recommended for use by state officials. This arrangement is by agreement between manufacturers and state representatives. In states not limiting the number of grades offered for sale, sales of grades recommended for use constitute from 4 to 85% of total sales of mixed goods.

The plant-food survey compiled by the Bureau of Plant Industry and National Fertilizer Association shows that 982 grades constituted 90.7% of tonnage of mixed goods in 1939, whereas 1,291 grades accounted for only 78% of total tonnage in 1934. Furthermore, 10 grades accounted for two-thirds or more of the consumption of mixed fertilizer in all but two states in 1939. These data show definite reduction in number of grades purchased and also that a comparatively few grades will satisfy the demand in most states.

In many cases, very slight differences exist between grades recommended in neighboring states and also in grades sold in such states as 0–14–6 vs. 0–14–7, 5–8–5 vs. 4–8–5, 4–8–7 vs. 4–8–8. Such minor differences could easily be eliminated by cooperative effort.

Agronomists who have not done so are urged to prepare a list of recommended grades. Even though faulty, such a list furnishes a basis for cooperation between the industry and state officials which will lead to a reduction in number of grades offered and a higher utilization of recommended grades. Annual or biennial conferences between agronomists of states with similar soil conditions and cropping systems and manufacturers serving the territory are urged in the interest of unity in grade recommendations and increased sale of recommended grades.

C. E. MILLAR, *Chairman*

Subcommittee on Methods of Fertilizer Application.—The Committee has continued to participate in the work of the National Joint Committee on Fertilizer Application. The extensive program on machine application of fertilizers has been continued and last year included 149 experiments in 24 states and involved 24 different crops.

Considerable attention is being given to the use of starter solutions at planting time, and thirteen experiments in seven states involving cabbage, sweet potatoes, tomatoes and Irish potatoes were conducted during the year.

A promising phase of the fertilizer placement work has dealt with the plowing under of fertilizers, either with or without organic residues, as a means of increasing the efficiency of fertilizer supplements to row application.

To an increasing degree interpretive studies of root development, movement of fertilizer salts in the soil, etc., are being made in connection with fertilizer placement studies in an effort to discover the fundamental principles involved.

ROBT. M. SALTER, *Chairman*

Subcommittee on Symptoms of Malnutrition in Plants.—The Committee is glad to report that its efforts to prepare and publish a book illustrating in color and describing the more important malnutrition symptoms of the major crop plants appear to be approaching a successful conclusion. The material for the book, most of which has been submitted and edited, has been prepared by the following chapter authors: Foreword by Gove Hambidge; background by George D. Scarseth and R. M. Salter; tobacco by J. E. McMurtrey, Jr.; cotton by H. P. Cooper; corn and small grains by G. N. Hoffer; potatoes by H. A. Jones and B. E. Brown; vegetable crops by J. J. Skinner; legume crops by E. E. DeTurk; deciduous fruits by O. W. Davidson; and citrus fruits by A. F. Camp, H. D. Chapman, George M. Bahrt, and E. R. Parker.

The prospectus announcing the book "Hunger Signs in Crops", was placed on display at the Chicago meeting of the Society. It describes in detail the proposed edition consisting of about 80 natural color plates and many additional illustrations. The descriptive material and illustrations will make up a book of about 300 pages.

It is expected that the book can be published at a cost of $2.00 per copy, prepublication price, with an edition of 10,000 copies.

The following procedure on publication has been recommended by the Committee and approved by the Executive Committee of the Society: First, that the book be published by the Committee on Fertilizers of the American Society of Agronomy with the cooperation of the National Fertilizer Association; and, second, that the copyright be assigned to the American Society of Agronomy and the National Fertilizer Association, but that the copyright, as printed in the publication, read merely, "Copyrighted in 1941". It is also recommended that there be an understanding with the copyright owners that any material included under the copyright can be used by the contributing authors at any later date as they may see fit.

J. E. McMURTREY, JR., *Chairman*

Subcommittee on Fertilizer Reaction.—The Committee on Fertilizer Reaction was established in 1935 when the fertilizer industry, the Association of Official Agricultural Chemists, and agronomists were studying the equivalent acidity of fertilizers. The initial work of the committee was devoted to promoting experiments aimed at the solution of several of the problems involved. Since the formation of the committee, the Association of Official Agricultural Chemists has adopted the Pierre Method for use in fertilizer control work. Six Southeastern states now require a guarantee for the acid-forming properties of fertilizers. Several other states determine and report the equivalent acidity of fertilizers. The fertilizer industry is guaranteeing the acid-forming properties of their fertilizers in many states, including a number that do not require such a guarantee. In the past five years, numerous field experiments have been conducted which involve a comparison of acid, neutral, and basic fertilizers. Many of these experiments are still in progress. Almost without exception the fertilizer acidity factor is given due consideration in planning new experiments and is also considered in the interpretation of data secured from older experiments. The results of extensive experiments in Mississippi were published in 1940 and showed an average increase of 90 pounds of seed cotton per acre due to addition of dolomite to make the fertilizer neutral.

In 1937, 1938, and 1939, the committee promoted studies on the availability of different sources of magnesia and the factors influencing the availability of magnesium in dolomite. These experiments were designed to help the Association of Official Agricultural Chemists arrive at a control method for available magnesium in fertilizers. The laboratory and greenhouse experiments have been completed and reported to the Association of Official Agricultural Chemists by Collins and Dawson. Some related work is being continued by Smith of Rhode Island, Associate Referee on magnesium for the A.O.A.C. as well as a member of this committee. Studies on this problem are being continued in the field at the Maine and Virginia Stations. None of the farm soils on which the experiments were located showed a response to magnesium in 1940.

Dr. W. H. Ross and his associates in the Division of Fertilizer Investigation of the U. S. Department of Agriculture has made a comprehensive study of the

reaction of magnesium compounds in fertilizers, including transformations of insoluble to soluble forms during the manufacture and storage processes. The results of these studies were reported at the 1940 meeting of the Fertilizer Division of the American Chemical Society and also at the Association of Official Agricultural Chemists.

The Subcommittee has encouraged field experiments on the influence of acid and neutral fertilizers on potato scab. Such experiments are in progress in North Carolina, Virginia, and Maine. More intensive studies on this and related subjects are being considered for next year's program. Such studies will include consideration of exchangeable calcium in the soil as well as the calcium content of the fertilizer.

F. W. PARKER, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

DURING the year, the following approved varieties were accepted by the Committee for registration on the basis of performance.

WHEAT

Marmin (Reg. No. 328) developed cooperatively by the Minnesota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

OATS

Fultex (Reg. No. 92), Ranger (Reg. No. 94), and Rustler (Reg. No. 95) developed cooperatively by the Texas Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Uton (Reg. No. 97) developed in cooperative experiments by the Utah Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Vicland (Reg. No. 93) developed by the Wisconsin Agricultural Experiment Station.

Huron (Reg. No. 96) developed by the Michigan Agricultural Experiment Station.

BARLEY

Wintex (Reg. No. 9) developed cooperatively by the Texas Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Compana (Reg. No. 10) developed cooperatively by the Montana Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Barbless (Reg. No. 11) developed by the Wisconsin Agricultural Experiment Station.

SORGHUMS

Coes (Reg. No. 77) and Highland (Reg. No. 78) developed cooperatively by the Colorado Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Descriptions of these varieties, and the yields and other records that form the basis for registration, are being prepared for publication in the JOURNAL.

In the Committee report submitted at the 1939 meetings at New Orleans, it was recommended that the registration of certain additional crops be approved and the Committee authorized to take necessary steps for their registration. It was also suggested that additional members be appointed on the Committee

to provide specialists qualified to act in the case of the new crops recommended for registration. No official action was taken on this recommendation, and it is again recommended that the Executive Committee approve the registration of improved varieties of red clover, sweet clover, alfalfa, flax, and rye, and that additional members be appointed to the Committee to care for their registration.

H. B. BROWN	H. K. HAYES	T. R. STANTON
J. A. CLARK	R. E. KARPER	G. H. STRINGFIELD
E. F. GAINES	W. J. MORSE	M. A. MCCALL, *Chairman*

RESOLUTIONS

THE Committee on Resolutions regrets to announce the passing of the following members of the American Society of Agronomy: Oliver W. Dynes and Harry P. Ogden of Tennessee, Burt L. Hartwell of Rhode Island, Jacob E. Metzger of Maryland, Adrian J. Pieters of Washington, D. C., John J. Pieper of Illinois, and B. D. Wilson of New York.

On behalf of the American Society of Agronomy the Committee make this announcement with deep sorrow and a feeling of real loss of the further achievements and companionship of our colleagues. Detailed accounts of the lives and attainments of these men are attached to this report, except where statements have already appeared in the pages of the JOURNAL.

O. S. AAMODT	J. D. LUCKETT, *ex-officio*
F. N. BRIGGS	F. D. KEIM, *Chairman*
R. I. THROCKMORTON	

OLIVER WESLEY DYNES

OLIVER WESLEY DYNES was born in Hornings Mills, Ontario, Canada, March 10, 1881, and died after an illness of a few hours in Knoxville, Tennessee, May 6, 1940. He graduated from North Dakota State College in 1907 and served his Alma Mater as Instructor and as Associate Professor in Agronomy, 1907–1914. He obtained his M.S.A. from Cornell University in 1912 and returned to that institution for further graduate work and as Instructor in Farm Crops, 1914–1920. He became Associate Professor of Agronomy at the University of Tennessee in 1920, Professor in 1925, and Head of the Department in 1928, and also Associate Agronomist of the Experiment Station in 1936. As a member of the American Society of Agronomy, he gave yoeman's service on various committees. He was a member of Alpha Zeta, Sigma Xi, and Phi Kappa Phi.

His career at Tennessee was that of a successful, sympathetic, and understanding teacher. He was beloved of the students to whom he was an inspiration and by whom he was dubbed affectionately "Daddy Dynes". His interest in his students was maintained after their campus days, and through the years he enjoyed the many warm friendships that grew out of the relationships between teacher and student.

His early background, environment, and experience were brought into an effective pattern with his scientific training and academic attainments. He was a well-trained scientist who implemented his knowledge into practical usefulness. Especially did he further the development and distribution of pure seed and he was particularly helpful to many engaged in the development of corn hybrids.

Professor Dynes was held in high esteem by his colleagues and academic associates. He was admired for his inherent modesty, kindly manner, and many lovable traits. His steadfast loyalty to his friends, and to his ideals was a dominant characteristic. Generosity, fairness in all his dealings, good will, and tolerance were characteristic traits that were supplemented with a keen delightful sense of humor. He laughed with, but never at others.

Oliver Dynes loved people in all walks of life and by them was loved. He enjoyed an extensive state-wide circle of friends, among those outside of teaching and research circles. His natural and unassuming bearing endeared him to those with whom he came into contact in his community life. He found time for and joy in his affiliation with the First Methodist Church of Knoxville, which he served actively as a member of the Official Board. He was active in Masonic organizations, from which he received many honors and by which he had been marked for further honor and distinction. He had served as Master of his Blue Lodge, High Priest of R.A.M., Thrice Illustrious Master of the Council, and Commander and Prelate of Knights Templar. At his death he was in the line of succession to become Grand Thrice Illustrious Master of the Grand Council of Tennessee. He was a 32° Mason and Secretary of Constance Chapter of Red Cross of Constantine. He was also a Shriner, member of the Royal Order of Jesters, and of Acacia Fraternity.

Professor Dynes married Carlotta Lillian Rowe of Dundalk, Ontario, Canada, September 5, 1917. She, one daughter, Velma, and one son, Russell, both now students in the University of Tennessee, survive him. To them he was the devoted husband and doting father. To them he left the heritage of the love and admiration of a community that appreciated his life of usefulness and helpfulness to others.

By those of us who knew him as fellow graduate student, teacher, academic associate, and loyal friend, the memory of Oliver Dynes will be cherished. His friendship was a blessing to those so fortunate as to come within its orbit.

In the death of Oliver Wesley Dynes, his family, friends, community, the University of Tennessee, and the state have suffered a loss, irreparable yet assuaged by the knowledge that this world is better because of his life of devoted service and the example set by him.—WALTER H. MACINTIRE.

BURT LAWS HARTWELL

BURT LAWS HARTWELL, formerly Director of the Rhode Island Agricultural Experiment Station, died at his home in Edgewood, Rhode Island, July 12, 1939. He is survived by his wife, May Louise Hartwell, and a daughter, Mrs. Roy B. Newton.

Doctor Hartwell was born near Littleton, Mass., December 18, 1865. His boyhood home was on a small Massachusetts farm. In 1889, he was graduated from Massachusetts State College and received his M.S. degree from the same school in 1901. He attended the fiftieth anniversary reunion of his class at Amherst in June, the month preceding his death. He received his Ph.D. degree from the University of Pennsylvania in 1903.

Doctor Hartwell came to the Rhode Island Agricultural Experiment Station in 1891 as Assistant Chemist. Later he attained the rank of Station Chemist and in 1912 he became Director of the Experiment Station. He served in this capacity until 1928, when he left the field of agricultural research. From 1928 until his death he was farm news editor of the Providence *Journal and Evening Bulletin*.

Doctor Hartwell's contributions to soils research are too well known to make it necessary to review them in detail. His outstanding contribution was perhaps his extensive research on soil acidity. Working with Dr. H. J. Wheeler in the early years of the Experiment Station, many fundamental projects on the response of different plants to soil acidity and methods of correcting this acidity were begun. In later years Doctor Hartwell was especially interested in the relation of the presence of toxic aluminum in the soil to soil acidity.

In addition to his extensive work on soil acidity and liming, Doctor Hartwell was also interested in the nutrient requirements of crop plants, and among his many publications are a large number dealing with this subject.

Doctor Hartwell became a member of the American Society of Agronomy soon after it was organized. He held a number of important committee positions and performed other assignments throughout his many years as an active member. He was elected a Fellow of the society in 1926.

In Doctor Hartwell's passing the science of agronomy lost one of its most faithful and outstanding workers.—T. E. ODLAND.

JACOB ELRY METZGER

JACOB ELRY METZGER, Director of the Maryland Agricultural Experiment Station and head of the Agronomy Department of the University of Maryland, died December 25, 1939, at Lake Worth, Florida, where he had gone for a vacation and rest. The cause of his death was coronary thrombosis.

Director Metzger was born on a farm near New Enterprise, Pa., July 30, 1882. Before entering Pennsylvania State College he taught several years in the elementary schools. He received his B.S. degree from Pennsylvania State College in 1911, in agricultural chemistry. The next three years were spent as an agricultural instructor in the high school at Fergus Fall, Minn. In 1914, he came to the Maryland Agriculture College, now the University of Maryland, as Professor of Agriculture Education and Supervisor of agricultural instruction for the Maryland State Department of Education. In 1917, he was appointed chairman of the Agronomy Department and continued in this capacity when the Soils and Agronomy Departments were combined in 1927. He received his A.M. degree from Johns Hopkins University in 1924. In 1935 he was made Assistant Director of the Experiment Station. On the retirement of Dr. H. J. Patterson in October 1937, he was appointed Acting Director, and in 1939, Director.

Although Director Metzger was especially interested in farm crops and rotations he had considerable interest in soils and related fields. This wide interest in agriculture is well demonstrated by the subject matter of the thirteen experiment station bulletins which he and his associates published. His greatest contribution to Maryland agriculture was that of a coordinator. His broad knowledge permitted him to see the value of related subjects and make suggestions for the improvement of the work of his associates. This outstanding ability was very noticeable when he assumed the directorship of the Experiment Station where his development of coordination between departments has resulted in the maximum of accomplishment from the funds expended. The Experiment Station staff and especially the members of his department regret very much that he was denied the pleasure of seeing the many benefits which will accrue from his efforts in the improvement of Maryland agriculture.

Director Metzger is survived by his widow, a brother, Dr. Irvin Metzger, M.D., of Pittsburgh, and three sisters, Mrs. Elry Furry, Mrs. Arch Furry, and Mrs.

Ira Kagarise, all living in Pennsylvania. Director Metzger was a fellow in the American Association for the Advancement of Science, member of the American Society of Agronomy, International Society of Soil Science, Masonic Fraternity, Kiwanis Club, Sigma Phi Sigma, Gamma Sigma Delta, Phi Kappa Phi, and Sigma Xi.—R. P. THOMAS.

HARRY P. OGDEN

HARRY P. OGDEN was born in Knoxville, Tennessee, November 10, 1888. He received his education in the Knoxville city schools and the University of Tennessee, being graduated from the latter institution in 1913 with the degree of Bachelor of Science in Agriculture. He died at his home in Knoxville, September 22, 1940, at the age of 52 years, after an illness of about one year.

He made a splendid scholastic record in the University and was elected to membership in the honor societies of Alpha Zeta and Phi Kappa Phi. After leaving the University he became head of the Science Department of the Clarksville High School; then Agricultural Agent for Montgomery County. He was next appointed to the position of Director of the Department of Agriculture at the State Teachers' College, Murfreesboro, where he conducted field experiments for the Experiment Station for several years. Returning to the University of Tennessee in 1926, he became Associate Agronomist at the Agricultural Experiment Station. In the experimental field he made contributions which will be of lasting benefit to the agricultural interests of the state and nation.

In particular he developed by breeding and selection three valuable varieties of soybeans, one of which has been named Ogden since his death. All three varieties are valuable because of their high production of both hay and seed. All are relatively fine stemmed but seldom lodge, and the seeds are exceptionally well retained in the pods, or "non-pop", to use a current expression.

Mr. Ogden was an especially valuable member of the station staff because of two outstanding qualities—an alert, practical mind and a devotion to detailed planning and careful conduct of experimental work. Another quality that endeared him to all members of the station staff was his willingness at all times to be of service by furnishing information and counsel in the solution of their problems so far as they were related to his knowledge and experience. Honest and sincere to the highest degree, cheerful and loyal, he will be missed by all his acquaintances.

He was married August 23, 1916, to Elsie Lapsley, who survives him with their children, Samuel Lapsley, Harry Kay, and Mary Frances.—C. A. MOOERS.

ADRIAN JOHN PIETERS

ADRIÁN JOHN PIETERS, formerly Principal Agronomist in Charge of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and a Fellow of the American Society of Agronomy, died at Sibley Hospital in Washington, April 25, 1940. He was in his seventy-fourth year.

Doctor Pieters retired from the Department in 1936 at the statutory age limit, but because of his wide knowledge of the use of soil-building crops the President twice reappointed him for a year's additional duty with the Bureau of Plant Industry and the Soil Conservation Service. Since 1938 he had been serving as Editor for the United States Golf Association Green Section.

Doctor Pieters was one of the early group of botanists, chemists, entomologists,

and agriculturists who, through their common interest in plants and soils, brought the science of agronomy into being. His own special training was in aquatic biology, but like his contemporaries, Lyon, Piper, Marbut, and others, his basic education was broad and his interests catholic. Thus, when the need arose, shortly after the turn of the century, he was fitted by circumstance and aptitude to become a "field-manager" or agronomist. Like these men, too, his personal qualities added stature to his technical equipment and gave distinction to his new profession. He personified dignity, culture, tolerance, and the judicial attitude, was indefatigable in the search for truth, and scorned sham or pretense whether social or intellectual. He was never known to loaf. Indeed, if criticism could be directed toward many of these men who created agronomy, it would be that they begrudged too earnestly the time spent in relaxation.

Doctor Pieters was of Dutch ancestry, a fact of which he was very proud. He was born in Alto, Wisconsin, the son of Roelof Pieters, a Dutch Reformed clergyman, and Hendricje Van Zwaluenburg Pieters. After a boyhood in Holland, Michigan, he graduated from the University of Michigan in 1894, then studied for a time at Cornell University. In 1895 he entered the Department of Agriculture as Assistant Botanist in Seed Investigations, under Gilbert Hicks. Almost immediately he was put in charge of a seed exhibit at the International exposition in Atlanta, the first exhibit of the kind ever shown by the United States Government. Curiously, one of the features of the exhibit was "a seed-scratching machine from Denmark", the forerunner by 20 years of seed scarifiers in America.

From 1900 to 1906 he was successively in charge of the Seed Testing Laboratory and the combined Offices of Seed and Plant Introduction and Distribution. In 1906 he resigned to engage in commercial seed production in California, establishing the firm that subsequently became the Pieters-Wheeler Seed Company. Having sold the seed business in 1910, he spent a year travelling in Europe and studying at Heidelburg University. He returned in 1912 to Ann Arbor, where he taught Forest Botany while working for his doctor's degree, which he received in 1915.

Shortly afterward he re-entered the Department of Agriculture, in the Office of Forage Crops to investigate the causes of widespread failure of the red clover crop. Soon he confirmed the belief that the principal cause was the use of seed from foreign countries, resulting in plants susceptible to disease and winter injury. He was instrumental, thereupon, in having restrictions placed on the importation of such seed.

It was during this study that Dr. Pieters was impressed with the futility of trying to make the soil fit the crop—by liming, principally—when the possibility of finding a crop to fit the soil had been only superficially investigated. He had in mind particularly the countless farms in the middle South whose owners were compelled, with meager resources, to get a living from depleted. acid soils. He began, therefore, a long series of tests of legumes of many kinds, culminating, in 1920, in the finding of *Lespedeza stipulacea*, a new annual species which he called, from the country of its origin, "Korean lespedeza". This plant proved of tremendous value for it was found to grow, produce, and persist on poor, sour soils throughout the South. The discovery rekindled interest in the lespedeza group with such success that by 1938 the seed crop of the lespedezas—about 190,000,000 pounds—equalled the seed crops of alfalfa, red clover, and alsike clover combined.

Doctor Pieters was an able and fluent writer, his publications, numbering more than 80 titles, covering many phases of seed production, green manuring,

forage crop production, and soil conservation. Two books, "Green Manuring—Principles and Practices" and "The Little Book of Lespedeza", and two voluminous digests of pasture literature were among these.

Agronomy may well be proud that such men were its progenitors. Their characters are their eulogies and their works their valedictories.—L. W. KEPHART.

BENJAMIN DUNBAR WILSON

THE untimely death of Benjamin Dunbar Wilson, Professor of Soil Technology in the New York State College of Agriculture at Cornell University, was received by all who knew him even casually, with profound regret. His death occurred at Warren, Ohio, on September 5, 1940, four days after an auto accident in which he received internal injuries that later proved fatal. In his passing his special field of scientific endeavor loses a faithful and conscientious worker; his immediate associates an amicable and inspiring colleague; and his wide circle of friends an active and loyal advocate. He was kindly, considerate, and approachable. These attributes will not soon be forgotten.

Born on October 14, 1889, in Lexington, Kentucky, of Virginia and South Carolina ancestry, Dr. Wilson was educated in the local schools of that city and entered the University of Kentucky in 1906, specializing in chemistry with Dr. F. E. Tuttle. Graduating in 1909 with a B.S. degree, he accepted a position as assistant chemist in the Kentucky State Agricultural Experiment Station, at the same time pursuing work for the degree of Master of Science in the University. This degree was awarded in 1914.

The next three years were spent by the young scientist at Cornell University as a graduate student and assistant with Dr. T. L. Lyon of the Department of Agronomy. In June, 1917, Cornell University granted him the degree of Doctor of Philosophy. This same year Dr. Wilson was made an Instructor and two years later Assistant Professor of Agronomy in the New York State College of Agriculture at Cornell. He occupied the latter position until 1934. During these years he worked on various research projects and in close association with Professor Lyon. In 1934, Dr. Wilson was raised to a full professorship of Agronomy at Cornell University.

The special scientific work that occupied Professor Wilson's attention during the last ten years of his life was a chemical investigation of the peat soils of New York State. After a preliminary survey which added much to the knowledge of the character and extent of New York peat deposits, laboratory work was begun on representative profile samples. The following titles selected from his list of publications indicate the nature of the work in general: "The Chemical Composition of the Muck Soils of New York", "Ionic Exchange of Peat Soils", "The Character of the Peat Deposits of New York", and "Loss of Plant Nutrients from Peat Soil".

It is doubtful whether anyone has contributed as much fundamental scientific information respecting the peat soils of New York, and incidentally of northeastern United States, as has Professor Wilson. Yet he felt his work barely begun and apparently had before him many years of fruitful endeavor. His loss to science is to be regretted.—H. O. BUCKMAN.

NOMINATING COMMITTEE

THE Nominating Committee made the following report: Dr. R. J. Garber, Bureau of Plant Industry, as representative of the Society to the Union of Biological Sciences; Dr. F. E. Bear, New Jersey Agricultural Experiment Station,

and Dr. W. B. Kemp, University of Maryland, as representatives of the Society on the Council of the American Association for the Advancement of Science; and for Vice President of the American Society of Agronomy, Dr. Richard Bradfield of Cornell University.

Upon motion the Secretary was instructed to cast one vote for these nominees and they were declared unanimously elected.

Respectfully submitted,
G. G. POHLMAN, *Secretary.*

GUIDE TO CONTRIBUTORS TO THE JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY

IN EDITING copy submitted for publication in the JOURNAL of the American Society of Agronomy every effort is made to preserve, so far as possible, the individuality of the author's style. It seems desirable, however, that a certain degree of uniformity in the general arrangement of material published in the JOURNAL should be maintained, and the following suggestions are offered as an aid to those who prepare manuscripts for publication in this JOURNAL.

Contributions to the JOURNAL are not arbitrarily restricted in length, but free publication for any one contribution is limited to 12 pages. Additional pages are charged for at the rate of $4.00 per page for each page beyond the 12-page limit, to and including 16 pages, and at the rate of $5.00 per page for each page beyond 16.

GENERAL STYLE

Prospective authors are requested to study recent issues of the JOURNAL as examples of the general style of writing which is maintained as a standard and, so far as possible, to conform to that standard in the preparation of their articles.

Clear, concise, correct statements are desired, rather than long, involved sentences. Generally an account of an investigation should be written in the third person. The use of the first or second person is permissible when the personal views of the author or reader are the point at issue rather than the facts in the case.

The title of the article should be as brief as possible, but at the same time should convey an accurate impression of the contents of the paper.

The copy should be on standard weight paper 8½ x 11 inches and should be double spaced. The ribbon copy should be submitted, never a carbon copy. Tables and legends for illustrations should be on separate sheets.

HEADINGS

The logical presentation of the results of an investigation presupposes a definite outline prepared in advance. This outline should comprise a few main headings sufficiently subdivided to indicate clearly the relationship of the various parts of the discussion to the whole.

For most purposes it will be unnecessary to provide headings of more than three grades, *viz.*, main headings, secondary headings, and side headings. Excessive refinement in subdividing the text should be avoided. The main headings and secondary headings stand in the center of the page and are set in different size type to show their relative importance. Side headings are printed in italics, and almost invariably indicate subdivisions under the secondary headings. Only a small amount of text matter, preferably not more than a page, should be covered by a side heading.

Each heading should contain a substantive and should indicate the thing or things described or discussed in the text.

TABLES

All tabular matter should receive close study in order that it may be presented in the clearest possible manner. Arabic numerals are used in numbering tables in the JOURNAL.

Brief, explanatory legends are preferred, but the legend should be complete in itself so that the table can stand without reference to the text.

An example of a good heading is as follows:

TABLE 2.—*Effect upon yield of potatoes of spraying with paris green.*

The following is not a satisfactory heading:

TABLE 2.—*Results of first experiment.*

Where decimals occur in tabulated data, and elsewhere in the article, ciphers should be used wherever significant figures are lacking, otherwise omit the decimal point, as 29.55, 32.00, etc. Also, the decimal point should be preceeded either by a significant figure or by a cipher, as for example 1.25 or 0.25; not .25.

The following example is offered as a desirable form for presenting tabular matter in the JOURNAL.

TABLE 4.—*Germination of freshly harvested seed of Poa pratensis composited from greenhouse plants.*

Germinating conditions*	Total germination at†		
	2 weeks %	4 weeks %	6 weeks %
20°–30° C	0	3	5
20°–30° C dark	1	9	11
Room temperature (22° to 26° C)	0	0	1
15°–30° C	11	47	77
15° C, dark, 10 days; then 20°–30° C	5	9	10
10°–30° C	14	87	91
10° C, dark, 10 days; then 20°–30° C	7	9	13
5°–30° C	0	4	5
5° C dark, 10 days; then 20°–30° C	0	28	29

*The lower temperature was maintained in darkness and the higher temperature in north light, except where otherwise noted.

†Each figure is the average of three replicates.

ILLUSTRATIONS

Drawings should be made on white drawing paper, or on blue or yellow lined graph paper. Do not use red or green lined graph paper unless it is imperative that the cross ruling be retained in the graph. All lines and lettering should be made with black india ink, and should be heavy enough to stand reduction to page size. The lettering along the ordinate or abscissa should be drawn in, as should all essential parts of the engraving.

The heading and general legend for the engraving should be typed on a separate sheet of paper, so it can be set up in type by the printer. Figures should be numbered consecutively, and should be referred to in the text by number, e.g., "Fig. 1."

In the case of photographs, contrasty, glossy black and white prints are desired. Only illustrations that will reproduce well in the JOURNAL and that make a distinct contribution to an understanding of the article will be accepted.

The JOURNAL bears the cost of zinc etchings and half-tones to the extent of $15.00 for each article, any costs in excess of this amount being charged back to the author.

QUOTATIONS AND REFERENCES

It is taken for granted in editing manuscript for the JOURNAL that the author assumes responsibility for the accuracy of quotations and literature citations, although occasionally these are verified where discrepancies are suspected.

In quotations the exact words of the original should be preserved. It is not essential in such cases, however, to reproduce typographical errors, or details of style, such as spelling, capitalization, or punctuation, which are at variance with the form approved by this JOURNAL, unless these differences are to be preserved for some particular purpose.

Literature citations if more than three should be grouped at the end of the article under the heading of "Literature Cited." Three citations or less should be given in footnotes.

Reference in the text to literature citations should be indicated by figures in parenthesis, for example, Brunson (1). The form of citation used in the JOURNAL is as follows:

1. BRUNSON, A. M. The relation of inheritance studies to corn improvement. Jour. Amer. Soc. Agron., 18:308–314. 1926.

In citations of experiment station publications the state names are abbreviated, as is also the United States Department of Agriculture, thus, N. Y. State Agr. Exp. Sta. Bul. 530; U. S. D. A. Bul. 1120.

CAPITALS

The word "state" should not be capitalized unless used with the state name, such as New York State. The word "county" should be capitalized if used before or after the name of the county, such as Ontario County. Terms applied to groups of states, as North Atlantic, South Atlantic, etc., should be capitalized, also terms denoting sections of the United States, as the West, the South, etc., but use eastern Gulf States, western New York, etc.

The terms "corn belt," "cotton belt," etc., should not be capitalized.

The words "experiment station" or "agricultural experiment station" should be capitalized only when used with the name of the instition, such as the Illinois Agricultural Experiment Station.

The names of genera, families, orders, etc., should be capitalized, but names of species should be written with lower case.

Words that have come into such common use that all thought of their origin has disappeared, such as paris green, bordeaux mixture, etc., should be written with lower case letters.

Also, use a. m. and p. m.

ORTHOGRAPHY

The Standard Dictionary should be used as the authority for spelling, compound words, etc., except where in conflict with recognized usage in the case of scientific terminology as indicated by leading scientific journals.

The forms "sulfur," "sulfate," and "sulfuric" are used in the JOURNAL. In expressing percentage the % sign is used. The word "plot" rather than "plat" is preferred.

NUMERALS

All amounts of ten or less should be spelled out, *except* enumerations of weight, measure, distance, clock time, money, percentage, degrees, proportion, and age, when figures should be used. For example, use six plots, not 6 plots; but write 6 pounds, not six pounds.

Figures should also be used in groups of enumerations where any one enumeration is in excess of ten. Also, treat alike all numbers in connected groups. For example, write 3, 7, and 12 varieties, not three, seven, and 12 varieties.

To avoid confusion where two numbers occur together, as "11 2-ounce tubers," write "eleven 2-ounce tubers."

Figures beginning a sentence should be spelled out, also both numbers of two related amounts at the beginning of a sentence, thus, "Ten to twelve kernels were selected."

Numbers of 1,000 or more should be written with the comma, except of course in the case of year numbers.

Use figures for decimal fractions and supply a cipher when there is no unit, as 0.25. Avoid a mixture of common and decimal fractions.

Dimensions should be expressed as "8 by 12 inches," not "8 x 12 inches." Also in expressing range use "10 to 20 inches," not "10–20 inches."

Where dates occur in the text the name of the month should be written out in full and the day without termination, as "January 15," not "Jan. 15th." In tables the name of the month should be abbreviated, thus "Jan. 15." Do not use the expression "1/15."

ABBREVIATIONS

Units of measure, such as grams, pounds, bushels, inches, gallons, etc., should be written in full in the text, but should be abbreviated when used in a table.

However, when necessary, use cm for centimeter, cc for cubic centimeter, mm for millimeter, cmm for cubic millimeter, mg for milligram, kg for kilogram, sp. gr. for specific gravity, p. p. m. for parts per

million, F for Fahrenheit, and C for Centigrade, both in the text and in tables.

In expressing hydrogen-ion concentrations use the form pH.

READING PROOF

Galley proofs of all articles published in the JOURNAL are sent to the authors, together with the manuscript, in ample time for a careful reading of the article in type before publication. Prompt attention to the reading of the proof and its return at the author's earliest convenience will be appreciated by the Editor, as the JOURNAL should not go to press until all proof has been returned.

In all cases the manuscript should be returned with the corrected proof.

Corrections on the galley proofs should be limited to only the most essential changes. The Editor exercises every care in the correction of typographical errors, but cannot assume responsibility for errors in statement of fact or in tabular matter that may have crept into the manuscript. Therefore, a careful reading by the author back to the original copy is highly desirable.

AGRONOMIC AFFAIRS

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Chairman of the Soils Section, C. E. KELLOGG, U. S. Dept. of Agriculture.
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Editor, J. D. LUCKETT, New York State Experiment Station.
Members of the Executive Committee, F. J. ALWAY, University of Minnesota, and R. J. GARBER, U. S. Dept. of Agriculture.

OFFICERS OF THE CROPS SECTION FOR 1941

A NOMINATING Committee was appointed by Dr. S. C. Salmon, Chairman of the Crops Section, and included O. S. Aamodt, Chairman, and F. D. Keim and Ide P. Trotter. At the business meeting of the Section held in Chicago, Ill., December 6, 1940, this Committee presented the following slate of officers for the Section for 1941 which was unanimously approved: For Chairman of the Section, C. J. Willard, Ohio State University, and as members of the Executive Committee of the Section, Glenn W. Burton of the U. S. Dept. of Agriculture and Karl S. Quisenberry of the University of Nebraska.

OFFICERS OF THE SOIL SCIENCE SOCIETY OF AMERICA FOR 1941

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NEWS ITEMS

DOCTOR MATTHEW DROSDOFF, formerly of the Division of Soil Survey, Bureau of Plant Industry, U. S. Dept. of Agriculture, has been transferred to the Field Laboratory for tung investigations at Gainesville, Fla. Dr. Walter Reuther, who received the Ph.D. degree at Cornell University in June 1940, was recently appointed Agent of the U. S. Dept. of Agriculture in the tung investigations and assigned to duty at the Field Laboratory at Gainesville.

ON NOVEMBER 11, Professor T. B. Hutcheson of the Virginia Agricultural Experiment Station, while on an elk hunt, suffered the misfortune of being pinned under a falling tree which resulted in fractured pelvic bones. He was taken to St. Elizabeth's Hospital at Pearisburg, Virginia, where he will likely remain until about Christmas.

A. M. BAISDEN, a graduate of Alabama Polytechnic Institute, who has been employed by the Virginia Agricultural Experiment Station as Junior Soil Surveyor since April 1938, was assigned the duties as Superintendent of the new branch experiment station being established in Orange County, Virginia, on December 12.

P. C. CONNER, who has been employed by the Virginia Agricultural Experiment Station as Junior Soil Surveyor since August 1938, has just accepted the position of Assistant Extension Forester for the Virginia Agricultural Extension Service, effective January 1, 1941. Mr. Conner is a native of Patrick County, Virginia, and a forestry graduate of North Carolina State College.

INDEX

Date of issue.	Date of issue.	Date of issue.